IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Group Art Unit 1753	:	PATENT APPLICATION
Examiner R. McDonald	:	
In re application of	:	**METHOD AND APPARATUS FOR PREPARING SPECIMENS FOR MICROSCOPY**
FISCHIONE ET AL.	:	
Serial No.: 10/633,130	:	
Filed: August 1, 2003	:	

Pittsburgh, Pennsylvania 15222

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Commissioner for Patents
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APPEAL BRIEF

Applicants submit the following Appeal Brief in response to the Final Office Action of May 6, 2010 ("Office Action"), which finally rejected claims 1, 3-7, 16-21, 24-31, 58-65, 68, 69, 73-75, 118, 120, 121, 124-135, 137-151 and 158-164 of the above-referenced application. Applicants timely filed a Notice of Appeal and a Pre-Appeal Brief Request for Review on August 5, 2010.

I. Real Party in Interest

The real party in interest is E.A. Fischione Instruments, Inc, which is a Pennsylvania corporation with a principal place of business at 9003 Corporate Circle, Export, PA 15632. E.A. Fischione Instruments, Inc. is the assignee of the above-referenced patent application.

II. Related Appeals and Interferences

There are no appeals or interferences related to this application.

III. Status of Claims

Claims 1, 3-7, 16-21, 24-31, 58-65, 68, 69, 73-75, 118, 120, 121 and 124-164, are currently pending in this application. Of the above claims, 152-157 have been withdrawn from consideration. Claims 1, 3-7, 16-21, 24-31, 58-65, 68, 69, 73-75, 118, 120, 121, 124-135, 137-151 and 158-164 stand rejected, and claim 136 has been objected to.

IV. Status of Amendments

All amendments presented in the case have been entered.

V. Summary of the Claimed Subject Matter

A. Brief Summary

The present invention relates to an apparatus for preparing a specimen for electron microscopy. In order to be accurately viewed through the microscope, each specimen, typically a 3mm disk, is prepared from a substrate material, cleaned, and then optionally

prepared by treatment of the surface to aid imaging. In the prior art, these operations are conducted by separate pieces of equipment and the specimen is transferred therebetween. Transfer of the specimen in ambient air conditions permits recontamination of the specimen as well as an opportunity for physical damage. The instant invention was developed to provide a closed environment for all of the preparation steps to be accomplished under constant and controlled conditions. Optimally, the specimen is placed within a device under vacuum conditions which remain constant for all of the operations. Repeated creation and releasc of vacuum is both inefficient and potentially deleterious to the condition of the specimen. One significant challenge to accomplishing this combination under constant vacuum and within a single vacuum chamber is the potential interference of one process with the others within the device.

The processes which are included within the device and which are performed within a single vacuum chamber include plasma cleaning, ion beam and plasma etching and ion beam sputter coating. Plasma cleaning requires that a plasma generator be connected to the vacuum chamber for plasma cleaning the specimen, an ion source must be connected to the vacuum chamber for etching the specimen, and a plasma etching assembly must connected to the vacuum chamber for plasma etching the specimen. The coating is performed using ion beam sputter coating techniques where an ion beam is directed at a target formed of a conductive material. The apparatus may further include a source of process gas connected to the plasma tube which may include oxygen or oxygen mixed with a non-reactive gas such as argon.

An additional challenge in achieving the multi-step processing described above is the movement of the specimen through the successive stages (or stations) within the

device. Many, if not all of the processing steps require the knowledge of the precise location and orientation of the sample so that accurate etching or coating thereof may be achieved. Recalling that the purpose of this preparation is for eventual imaging in an electron microscope, accuracy must be achieved to an extremely high level of precision. The claims therefore include, independently, a positioning device which is adapted to precisely locate and align the specimen in a three dimensional space. Each of the claims requires the use of a beam to locate an accurate, fixed position in *three dimensional space* from which all relative motion and displacement of the specimen may be calculated.

B. Direct Mapping of Independent Claim Elements to Specification

A direct mapping of the elements of the independent claims to the specification are as follows:

1. (Rejected) An apparatus for preparing a specimen for microscopy, comprising:

a plasma generator for plasma cleaning said specimen *(Page 17, lines 14-24; page 20, line 4 - page 23, line 4)*;

means for removing material from said specimen *(Page 24, line 10 - page 25, line 19)*;

means for coating said specimen with a conductive material *(Page 23, line 5 - page 24, line 9)*; and

means for plasma etching said specimen *(Page 24, line 10 - page 26, line 11; page 33, lines 5- 9)* which includes the selective spatial isolation of said means for plasma etehing said specimen and said specimen from said plasma

generator, said means for removing material and said means for coating said specimen when said means for plasma etching said specimen is operational *(Page 28, lines 11-18; page 34, line 22 - page 35, line 20)*;

wherein said plasma cleaning of said specimen and said coating of said specimen may be performed in a single process chamber under continuous vacuum conditions (*Page 33, line 22 - page 34, line 4 and generally throughout the specification).*

158. (Rejected) An apparatus for preparing a specimen for microscopy, comprising:

a processing chamber *(Page 17, lines 14-24; page 20, line 4 - page 23, line 4)*;

a sample stage, said sample stage being moveable to one or more processing positions inside said processing chamber, said processing position being defined by three dimensional coordinates *(Page 26, line 12 - page 27, line 8)*; and

means for detecting a first position of a surface of said specimen within said processing chamber *(Page 36, line 22 - page 37, line 18)*;

wherein said sample stage is moved automatically to said one or more processing positions remote from said first position in any of three dimensions and at an angle relative to a beam impinging thereon *(Page 36, line 5 - page 37, line 18 and generally throughout the specification).*

161. (Rejected) An apparatus for preparing a specimen for microscopy, comprising:

a processing chamber *(Page 17, lines 14-24; page 20, line 4 - page 23, line 4)*;

a sample stage, said sample stage being moveable to one or more processing positions inside said processing chamber, said processing positions being defined by three dimensional coordinates *(Page 26, line 12 - page 27, line 8)*; and

a beam generating device and a beam sensor supported by said processing chamber, said beam generating device and said beam sensor being used to detect a first position of a surface of said specimen within said processing chamber *(Page 36, line 5 - page 37, line 18)*;

wherein said sample stage is moved automatically to said one or more processing positions remote from said first position in any of three dimensions and at an angle relative to said beam generating device *(Page 36, line 5 - page 37, line 18 and generally throughout the specification)*.

VI. Grounds of Rejection to Be Reviewed on Appeal

Applicants present the following concise statement of each of the grounds of rejection presented for review:

A. Whether claims 1, 3-7, 16-21, 24-31, 58-65, 68, 69, 73-75, 118, 121, 124-137 and 139-151 are indefinite under 35 U.S.C. § 112, first paragraph, for lack of written description.

B. Whether claims 1, 3-7, 16-21, 24-31, 58-65, 68, 69, 73-75, 118, 120, 121, 124-137, 139-151 and 158-164 are obvious under 35 U.S.C. § 103(a) over various combinations of Siebert, U.S. Pat. No. 4,858,556, Moslehi, U.S. Pat. No. 6,051,113, Mahler, U.S. Pat. No. 4,595,483, Miyoshi, U.S. Pat. No. 6,325,857, Ameen, et al., U.S. Pat. No. 6,143,128, Chang, et al., U.S. Pat. No. 6,434,814, Mitro, et al., U.S. Pat. No. 5,922,179, Kobayashi, et al., U.S. Pat. No. 5,340,460, Holland, U.S. Pat. No. 5,311,725, Nomura, et al., U.S. Pat. No. 6,641,703, Chang, et al., U.S. Pat. No. 6,434,814, Hurwitt, U.S. Pat. No. 3,756,939, and Baldwin, et al., U.S. Pat. No. 6,419,802.

VII. Argument

A. Claims 1, 3-7, 16-21, 24-31, 58-65, 68, 69, 73-75, 118, 121, 124-137 and 139-151 are not indefinite under 35 U.S.C. § 112, first paragraph, and are adequately supported by the written description in the specification.

The Examiner states that there is no support for the phrase "selective spatial isolation of said means for plasma etching said specimen and said specimen from said plasma generator, said means for removing material and said means for coating said specimen when said means for plasma etching said specimen is operational." Specifically, the Examiner inquires as to what element isolates the means for etching from each of the devices. *See Office Action dated May 6, 2010, page 2.* Applicant has previously drawn the Examiner's attention to portions of the specification which discloses several examples of the isolation of the etching means from each of the other devices. *See Applicant's response dated February 8, 2010, page 23.* For example, the specification generally describes moveable shutters or baffles positioned in front of viewing window 200 and magnetron sputtering head 105 to "further protect from deposition of foreign material when not in use." *See Specification page 28, lines 11-12.*

More specifically, the specification states:

> "Moveable shutter 905 is provided within vacuum chamber 805 and is adapted to be moved, preferably automatically, to a position that covers aperture 900 when plasma cleaning is not being performed to protect the components of the plasma generator from contamination when the other specimen preparation processes described herein are being performed. Referring to Figure 11, when specimen 835 is to be plasma cleaned, sample stage 850 is moved, preferably automatically, to a position as shown in Figure 11 through operation of the appropriate stepper motors. In the position shown in Figure 11, specimen 835 is positioned adjacent aperture 900 and shutter 905 is moved to the open position."

Specification, page 39, line 17 - page 40, line 3. Additionally:

> "[m]oveable shutter 945 is provided in vacuum chamber 805 and is adapted to be moved, preferably automatically, to a position that covers aperture 940 when plasma etching is not being performed to protect the components of RIE assembly 920 from contamination when the other specimen preparation processes described herein are being performed."

Specification, page 41, line 21 - page 42, line 2 and see Figure 11.

Figure 1 also shows a transfer rod 30 which accommodates one or more sub-mounted specimens 3. Transfer rod 30 moves back and forth between *two separate* chambers-plasma chamber 15 and etching and coating chamber 20. *See Specification page 18, line 21 to page 19, line 1.*

Figure 6 illustrates an apparatus including two vacuum vessels 610 and 620. The port for specimen introduction and removal, the plasma generator and RIE electrode are located in vessel 610, while the ion gun and sputter target are located in vessel 620. The two vessels are joined by a shared valve 630, which serves to *isolate* and/or connect the two vessels. *See Specification page 34, lines 5-15.* The specification also describes an additional embodiment where the valve 630 is replaced by a moveable baffle that, when closed, blocks the line-of-sight travel between vessels 610 and 620.

Applicant respectfully asserts that specification provides sufficient description of the portion of the claimed apparatus responsible for isolating the means for etching from the other devices. The claims therefore satisfy the written description requirement of 35 U.S.C. § 112, first paragraph.

B. Claims 1, 3-7, 16-21, 24-31, 58-65, 68, 69, 73-75, 118, 120, 121, 124-137, 139-151 and 158-164 are not obvious under 35 U.S.C. § 103(a) over various combinations of Siebert, U.S. Pat. No. 4,858,556, Moslehi, U.S. Pat. No. 6,051,113, Mahler, U.S. Pat. No. 4,595,483, Miyoshi, U.S. Pat. No. 6,325,857, Ameen, et al., U.S. Pat. No. 6,143,128, Chang, et al., U.S. Pat. No. 6,434,814, Mitro, et al., U.S. Pat. No. 5,922,179, Kobayashi, et al., U.S. Pat. No. 5,340,460, Holland, U.S. Pat. No. 5,311,725, Nomura, et al., U.S. Pat. No. 6,641,703, Chang, et al., U.S. Pat. No. 6,434,814, Hurwitt, U.S. Pat. No. 3,756,939, and Baldwin, et al., U.S. Pat. No. 6,419,802.

1. Claim 1

The Examiner's primary argument against patentability of Claim 1 and its dependencies combines Siebert, Moslehi, Mahler and Myoshi. More specifically, Siebert is cited for teaching a means of removal of material and means for coating the specimen in a single process chamber. Reference is further made to an incidental statement of Siebert which states that other energy sources may be utilized in the apparatus. The Examiner admits that Siebert does not teach the inclusion of plasma cleaning, plasma etching, coating the specimen with conductive material or the selective isolation of portions of the device while plasma etching is in operation. The Examiner then cites Moslehi for plasma cleaning and coating. Mahler is cited for teaching coating the specimen and plasma etching under continuous vacuum conditions. Miyoshi is cited for teaching the use of a shutter to isolate an etching means. The Examiner concludes by

stating that it would be obvious to combine all of these references because Siebert "allows for performing process [sic] in a single chamber and protecting the other means from the etching device."

The claimed invention requires that the plasma etching functionality be ***isolated*** from the other component functionalities of the device ***when said means for plasma etching said specimen is operational***. As explained previously, this spatial limitation requires that the highly corrosive etching hardware be separated physically from the other functional devices. Applicant continues to contend that this is not taught nor suggested in the prior art. The Siebert reference does identify a shutter which rotates to expose the specimen to the appropriate operative hardware, and which is stated to provide additional substrate protection. However, no further disclosure is made and Fig. 7 merely identifies it as a standalone, line of sight shield between the various operative hardware and the specimen. Moreover, the testing or detection devices of the Siebert reference are still contained within the chamber with the specimen. The shutter is not shown to spatially separate the specimen and plasma etching mechanism from the other operative components. The Examiner relies on a single, nonspecific reference to other devices, "the sources 18 may be any of a number of different types of sources. . ." (col. 12, lines 24-25) as the basis for linking ***two or three*** additional references to arguably find all of the elements of the claimed invention.

KSR International Co. v. Teleflex Inc., 550 U.S. 398, 127 S.Ct. 1727, 167 L.Ed.2d 705 (2007) disposes of the heretofore enunciated standard requiring a teaching, suggestion or motivation to combine references, in order to avoid improper hindsight reconstruction. *Id.* at 1742. The TSM standard has not been completely disavowed,

however. A flexible TSM standard has been approved by the United States Court of Appeals for the Federal Circuit, following the KSR ruling.

> [T]he Supreme Court advised that 'common sense' would extend the use of customary knowledge in the obviousness equation: 'A person of ordinary skill is also a person of ordinary creativity, not an automaton.' *Id.* Thus, the Supreme Court set aside any 'rigid' application of the TSM test and ensured use of customary knowledge as an ingredient in that equation. The Supreme Court observed that this court had also 'elaborated a broader conception of the TSM test than was applied in [KSR]. *Id.* at 1743. Specifically the Court referred to *DyStar Textilfarben GmbH & Co. v. C.H. Patrick Co.*, wherein this court noted: '[o]ur suggestion test is in actuality quite flexible and not only permits, but requires, consideration of common knowledge and common sense.' 464 F.3d 1356, 1367 (Fed.Cir.2006) (emphasis original). The Court suggested that this formulation would be more consistent with the Supreme Court's restatement of the TSM test. *KSR Int'l Co.,* 127 S.Ct. at 1739. In any event, as the Supreme Court suggests, a flexible approach to the TSM test prevents hindsight and focuses on evidence before the time of invention, see, e.g., *In re Rouffet,* 149 F.3d 1350, 1357 (Fed.Cir.1998), without unduly constraining the breadth of knowledge available to one of ordinary skill in the art during the obviousness analysis.

In re Translogic Technology, Inc., 504 F.3d 1249, 1260 (Fed.Cir. 2007). Pre-TSM courts utilize standards which are entirely consistent with this formulation. *In re Fine,* 837 F.2d 1071, 1073-75 (Fed.Cir. 1988), states:

> To reach a proper conclusion under § 103, the decisionmaker must step backward in time and into the shoes worn by [a person having ordinary skill in the art] when the invention was unknown and just before it was made. In light of all the evidence, the decisionmaker must then determine whether ... the claimed invention as a whole would have been obvious at that time to that person. The answer to that question partakes more of the nature of law than of fact, for it is an ultimate conclusion based on a foundation formed of all the probative facts . . . It can satisfy this burden only by showing some objective teaching in the prior art or that knowledge generally available to one of ordinary skill in the art would lead that individual to combine the relevant teachings of the references . . . It is essential that 'the decisionmaker forget what he or she has been taught at trial about the claimed invention and cast the mind back to the time the invention was made . . . to occupy the mind of one skilled in the art who is presented only with the references, and who is normally guided by the then-accepted wisdom in the art.' One cannot use hindsight

> reconstruction to pick and choose among isolated disclosures in the prior art to deprecate the claimed invention (citations omitted).

In this case, as in *Ortho-McNeil Pharmaceutical, Inc. v. Mylan Laboratories, Inc.*, 520 F.3d 1358 (Fed.Cir. 2008), the references amply support a finding of nonobviousness. "The challenges of this inventive process would have prevented one of ordinary skill in this art from traversing the multiple obstacles to easily produce the invention in light of the evidence available at the time of invention." *Id.* at 1365. Siebert merely discloses the potential use of other sources. It contains no further disclosure, nor any separation therebetween. Figure 2 identifies the different sputter and ion beam sources as all interchangeable above a rotating shutter. The shutter itself is merely a movable shade to temporarily block the emissions of the source from the specimen. Miyoshi discloses a chamber which is utilized to prepare a reactive material for exposure to the specimen. The chamber is sealed by a movable shutter. The shutter is closed to allow the reactant materials to enter the chamber in a controlled environment. When the reaction has produced the appropriate products, **the shutter is opened and the specimen is exposed to the material. The shutter is therefore utilized to** encapsulate the reactive materials, not shield the specimen or other fixtures in the chamber. Contrary to the Examiners assertions, the shutter of Miyoshi *would not* function to isolate one means from another so that the different processes do not affect the functionalities of the other components. In the most recent office action, the Examiner has stated, on Page 8, "[r]egarding isolating the etching means form[sic] the other means (claim 1), Miyoshi teach[sic] a shutter which isolates [sic] means from an etching means" (referring to column 9, lines 62-68 and column 10, lines 1-4. This specific reference to Miyoshi teaches that the shutter is utilized to shield the catalyzer holder 2 (the source) from the

operation of the cleaning device 5. ***The shutter 4 is utilized to shield the catalyzer (source) from the operation of the cleaner which is utilized to clean the interior of the chamber and specimen stage when the device is not in operational use to perform any etching, cleaning or coating of a specimen.*** Neither Siebert nor Miyoshi teaches or suggests that a shutter may be utilized to shield different reactive components or fixtures during the use of other source components within a closed vacuum chamber during the operation of a source on the specimen. This is not a case where one element has merely been substituted for another.

A rote combination of the teachings of Siebert, Moslehi, Mahler and Miyoshi would not result in the claimed invention. The combination yields more than a predictable result, as required by *United States v. Adams,* 383 U.S. 39, 50-51 (1966), cited with approval by *KSR.* The claimed invention combines the heretofore disparate functionalities of plasma cleaning, etching with plasma and otherwise, and coating are all performed in the same chamber under continuous vacuum. This is especially true of plasma etching, which does not readily combine with other processes. None of these references recognizes the need to isolate the plasma etching function during operational etching of the specimen with particularity, nor do they recognize any need for separation of the functions. To stuff all of the identified features in a box does not yield a useful device. Even placing the Miyoshi reaction chamber into a common vacuum chamber would not yield the claimed device, as the device segregates the plasma etching function ***while operational with respect to the substrate***, and not as a preparatory or ***maintenance*** step.

As stated by the Examiner, some hindsight is necessary in any obviousness evaluation. However, the MPEP clearly states:

> Knowledge of applicant's disclosure must be put aside in reaching this determination, yet kept in mind in order to determine the 'differences,' conduct the search and evaluate the 'subject matter as a whole' of the invention. The tendency to resort to 'hindsight' based upon applicant's disclosure is often difficult to avoid due to the very nature of the examination process. However, impermissible hindsight must be avoided and the legal conclusion must be reached on the basis of the facts gleaned from the prior art.

MPEP §2142. Applicant respectfully reasserts that the Examiner is applying impermissible hindsight in the evaluation of the above-cited prior art references. None of the prior art references, either alone or in combination, teaches or suggests a shutter or other selective spatial isolation to shield different reactive components or fixtures during the use of other source components during the operation of a source on the specimen. Withdrawal of the rejection is respectfully requested.

2. Claims 158, 161

The Examiner has rejected claims 158, 161 and their dependencies based upon the teachings of Moslehi. More specifically, the Examiner states that Moslehi teaches a position sensor for detecting a position of the specimen, and that the sample stage can be moved to one or more processing positions remote from the first position in any of the three dimensions. The Examiner admits that Moslehi does not teach the use of a beam impinging upon the sample stage to make such detection, nor does Moslehi teach the ability to hold the specimen at an angle to such a beam. The Examiner relies upon Mitro

for the teaching of rocking the specimen in combination with Moslehi to reject the claimed requirement of holding the substrate at an angle. Baldwin is cited for the utilization of a beam to detect position.

Referring first to Moslehi, the reference discloses an indexing chuck which incorporates a stepper motor for positional reference. Each stepper motor has a preset zero value associated with a location and tracks relative movement from that physical location. Rotation of the motor is indexed so that return to the preset zero position is achieved by counting the number of "steps" from the zero position. Movement may be made only in the preset, two dimensional *rotational motion* provided by the motor. Three dimensional movement is provided by two cooperative stepper motors, which allow for rotation of a shaft as the two dimensional movement described earlier, coupled with the upward and downward movement of the shaft associated with a second stepper motor. Moslehi does not teach or suggest the use of a beam as a reference point, as required by the instant claims.

Mitro discloses an apparatus which again provides a shaft driven rotational motion for movement of specimen relative to a etching or coating device. The Examiner cites it for "disposing the substrate at an angle" and "uniform coating." Mitro does not, however, disclose the use of a beam as a reference point as required by the instant claims.

Baldwin is cited for the use of a beam to detect position. Baldwin, however, does not teach or suggest the use of a beam to detect *position.* Baldwin teaches the use of a beam to detect the *deposition thickness of material on the substrate. Col. 4, lines 24-31.* Baldwin is therefore not capable of determining where a device is in three dimensional

space, but merely the size of the material incident to the beam. Moreover, Baldwin is not capable of determining the angle of incidence of the beam to the detected material.

In light of the foregoing, it would not be obvious to combine Baldwin, Moslehi and Mitro to obtain the claimed invention, *nor does the combination of the three references result in a teaching or suggestion of the claimed invention.* There is no teaching, alone or in combination, of the use of a beam to detect the position of a device in three dimensional space. Nor is there a teaching of using such a beam to align such a device at an angle incident to the beam. For the reasons stated above, Applicants respectfully submit that the rejection of claims 1, 3-7, 16-21, 24-31, 58-65, 68, 69, 73-75, 118, 120, 121, 124-135, 137-151 and 158-164 is overcome, and reversal of the rejection thereof is respectfully requested along with a holding that each of the claims is allowable.

Respectfully submitted,

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APPENDICES

APPENDIX OF CLAIMS

1. (Rejected) An apparatus for preparing a specimen for microscopy, comprising:

a plasma generator for plasma cleaning said specimen;

means for removing material from said specimen;

means for coating said specimen with a conductive material; and

means for plasma etching said specimen which includes the selective spatial isolation of said means for plasma etching said specimen and said specimen from said plasma generator, said means for removing material and said means for coating said specimen when said means for plasma etching said specimen is operational;

wherein said plasma cleaning of said specimen and said coating of said specimen may be performed in a single process chamber under continuous vacuum conditions.

2. (Cancelled)

3. (Rejected) An apparatus according to claim 1, wherein said means for removing comprises means for etching said specimen using an ion beam.

4. (Rejected) An apparatus according to claim 3, wherein said means for etching comprises an ion source for directing said ion beam at said specimen.

5. (Rejected) An apparatus according to claim 4, wherein said means for etching further comprises a source of process gas positioned adjacent said ion source.

6. (Rejected) An apparatus according to claim 1, said means for coating comprising a magnetron sputtering device.

7. (Rejected) An apparatus according to claim 1, said means for coating comprising an ion source for directing an ion beam at a target, said target being formed of said conductive material.

8. (Cancelled)

9. (Cancelled)

10. (Cancelled)

11. (Cancelled)

12. (Cancelled)

13. (Cancelled)

14. (Cancelled)

15. (Cancelled)

16. (Rejected) An apparatus according to claim 1, wherein said plasma generator comprises a plasma tube, a coil wrapped around said plasma tube, and an RF power supply connected to said coil.

17. (Rejected) An apparatus according to claim 16, further comprising a source of process gas including oxygen connected to said plasma tube, said plasma cleaning being performed using said process gas.

18. (Rejected) An apparatus according to claim 17, said process gas further including argon.

19. (Rejected) An apparatus according to claim 18, said process gas comprising a mixture of 75% argon and 25% oxygen.

20. (Rejected) An apparatus according to claim 17, said process gas further including a non-reactive gas.

21. (Rejected) An apparatus according to claim 1, further comprising a vacuum pump connected to said process chamber for evacuating said process chamber to a selected vacuum level.

22. (Cancelled)

23. (Cancelled)

24. (Rejected) An apparatus according to claim 21, further comprising an oil-free vacuum pump for controlling said vacuum conditions.

25. (Rejected) An apparatus according to claim 24, said oil-free vacuum pump selected from the group consisting of oil-free diaphragm pumps, molecular drag pumps, turbomolecular drag pumps, molecular drag pumps backed by a diaphragm pump, turbomolecular drag pumps backed by a diaphragm pump, cryosorption pumps, reciprocating piston pumps, scroll pumps, screw pumps, claw pumps, non-oil sealed single and multistage piston pumps, and rotary lobe pumps.

26. (Rejected) An apparatus according to claim 1, further comprising a specimen stage for holding said specimen, said specimen stage being adapted to tilt said specimen with respect to said means for removing, said specimen stage being rotatable about an axis of rotation generally perpendicular to a plane defined by a surface of said specimen when said specimen is held by said specimen stage.

27. (Rejected) An apparatus according to claim 26, further comprising means for cooling said specimen stage.

28. (Rejected) An apparatus according to claim 26, said specimen stage being selectively moveable along said axis of rotation.

29. (Rejected) An apparatus according to claim 1, said chamber further comprising a specimen stage for holding said specimen, said specimen stage being adapted to tilt said specimen with respect to said means for removing, said specimen stage being rotatable about an axis of rotation generally perpendicular to a plane defined by a

surface of said specimen when said specimen is held by said specimen stage.

30. (Rejected) An apparatus according to claim 1, said chamber further comprising a cold trap.

31. (Rejected) An apparatus according to claim 1, said chamber further comprising a crystal oscillator for measuring an amount of said conductive material that is deposited on said specimen.

32. (Cancelled)

33. (Cancelled)

34. (Cancelled)

35. (Cancelled)

36. (Cancelled)

37. (Cancelled)

38. (Cancelled)

39. (Cancelled)

40. (Cancelled)

41. (Cancelled)

42. (Cancelled)

43. (Cancelled)

44. (Cancelled)

45. (Cancelled)

46. (Cancelled)

47. (Cancelled)

48. (Cancelled)

49. (Cancelled)

50. (Cancelled)

51. (Cancelled)

52. (Cancelled)

53. (Cancelled)

54. (Cancelled)

55. (Cancelled)

56. (Cancelled)

57. (Cancelled)

58. (Rejected) An apparatus according to claim 1, said plasma etching further comprising capacitive discharge plasma etching.

59. (Rejected) An apparatus according to claim 58, said means for plasma etching comprising a first electrode supported by said process chamber and a second electrode supported by said process chamber, said first and second electrodes defining a gap therebetween for receiving said specimen.

60. (Rejected) An apparatus according to claim 59, said first and second electrodes each comprising a substantially planar electrode, said first electrode and said

second electrode being substantially parallel to one another.

61. (Rejected) An apparatus according to claim 60, further comprising a specimen stage for holding said specimen, said specimen stage being supported by said process chamber, at least a portion of said specimen stage being said first electrode.

62. (Rejected) An apparatus according to claim 61, said specimen stage being moveable in a direction substantially perpendicular to a planar surface of said first electrode.

63. (Rejected) An apparatus according to claim 61, said second electrode being moveable in a direction substantially perpendicular to a planar surface of said second electrode.

64. (Rejected) An apparatus according to claim 59, further comprising an alternating voltage source connected to said first and second electrodes for generating an electric field within said gap, said electric field generating a plasma from a gas introduced into said gap.

65. (Rejected) An apparatus according to claim 1, said plasma etching further comprising inductively coupled plasma etching.

66. (Cancelled)

67. (Cancelled)

68. (Rejected) An apparatus according to claim 3, further comprising means for ion beam etching said specimen, wherein said ion beam etching may be performed under said continuous vacuum conditions.

69. (Rejected) An apparatus according to claim 68, further comprising an ion source for directing an ion beam at said specimen, said ion beam etching said specimen, wherein said etching of said specimen with said ion beam may be performed under continuous vacuum conditions.

70. (Cancelled)

71. (Cancelled)

72. (Cancelled)

73. (Rejected) An apparatus according to claim 69, wherein said ion source may selectively direct said ion beam at said specimen for ion beam etching said specimen under said continuous vacuum conditions.

74. (Rejected) An apparatus according to claim 73, further comprising a specimen stage for holding said specimen, said specimen stage being moveable between a first position in which said specimen is within a path of said ion beam such that said ion beam is directed at and impinges upon said specimen and a second position in which said

specimen is outside of said path such that said ion beam is directed at and impinges upon said target.

75. (Rejected) An apparatus according to claim 74, said specimen stage being adapted to tilt said specimen with respect to said ion source, said specimen stage being rotatable about an axis of rotation generally perpendicular to a plane defined by a surface at said specimen when said specimen is held by said specimen stage.

76. (Cancelled)

77. (Cancelled)

78. (Cancelled)

79. (Cancelled)

80. (Cancelled)

81. (Cancelled)

82. (Cancelled)

83. (Cancelled)

84. (Cancelled)

85. (Cancelled)

86. (Cancelled)

87. (Cancelled)

88. (Cancelled)

89. (Cancelled)

90. (Cancelled)

91. (Cancelled)

92. (Cancelled)

93. (Cancelled)

94. (Cancelled)

95. (Cancelled)

96. (Cancelled)

97. (Cancelled)

98. (Cancelled)

99. (Cancelled)

100. (Cancelled)

101. (Cancelled)

102. (Cancelled)

103. (Cancelled)

104. (Cancelled)

105. (Cancelled)

106. (Cancelled)

107. (Cancelled)

108. (Cancelled)

109. (Cancelled)

110. (Cancelled)

111. (Cancelled)

112. (Cancelled)

113. (Cancelled)

114. (Cancelled)

115. (Cancelled)

116. (Cancelled)

117. (Cancelled)

118. (Rejected) An apparatus according to claim 1, further comprising a load lock chamber connected to said process chamber.

119. (Cancelled)

120. (Rejected) An apparatus according to claim 68, said etching comprising reactive ion beam etching, said apparatus further comprising a source of reactive process gas connected to said ion source.

121. (Rejected) An apparatus according to claim 58, said plasma etching utilizing a plasma generated by capacitive discharge, said plasma etching assembly further comprising an electrode and an alternating voltage source connected to said electrode.

122. (Cancelled)

123. (Cancelled)

124. (Rejected) An apparatus according to claim 59, wherein one or more of a size of said gap and a power of said alternating voltage source are automatically controlled based on parameters set by a user.

125. (Rejected) An apparatus according to claim 124, said plasma etching assembly further comprising two or more gas inlets, said process gas comprising a mixture of two or more process gasses selected by a user.

126. (Rejected) An apparatus according to claim 125, wherein said process gasses further comprise at least one of O_2, CF_4 and CHF_3.

127. (Rejected) An apparatus according to claim 1, said means for plasma etching further comprising two or more gas inlets, said plasma etching of said specimen utilizing a plasma generated from a mixture of two or more process gasses selected by a user.

128. (Rejected) An apparatus according to claim 1, said means for plasma etching being usable to plasma clean said specimen by generating a plasma from a process gas including oxygen.

129. (Rejected) An apparatus according to claim 1, wherein coating comprises ion beam sputter coating, said means for coating comprising a target formed of said

conductive material, said ion source directing said ion beam at said target.

130. (Rejected) An apparatus according to claim 129, said means for coating further comprising a lever supported by said vacuum chamber, said lever holding said target, said lever being selectively moveable into a position in which said ion beam is directed at said target.

131. (Rejected) An apparatus according to claim 1, said means for coating comprising a plurality of targets, each of said targets being formed of a conductive material, said ion source directing said ion beam at a selected one of said targets.

132. (Rejected) An apparatus according to claim 131, said means for coating further comprising means for moving said selected one of said targets from a covered position to an exposed position.

133. (Rejected) An apparatus according to claim 131, said means for coating further comprising a lever supported by said vacuum chamber, said lever holding said plurality of targets, said lever being selectively moveable into a position in which said ion beam is directed at said selected one of said targets.

134. (Rejected) An apparatus according to claim 133, said plurality of targets being held by a target holder, said target holder being moveable among a plurality of positions, each of said positions exposing one of said targets and covering a remaining

one or more of said targets.

135. (Rejected) An apparatus according to claim 134, said target holder being rotatably supported by said lever, said target holder being rotatable among said plurality of positions.

136. (Objected To) An apparatus according to claim 135, said target holder further comprising a plurality of pins, said vacuum chamber supporting an arm, said target holder being selectively rotated by contact between said arm and any one of said pins.

137. (Rejected) An apparatus according to claim 133, further comprising means for selectively exposing said selected one of said targets and covering a remaining one or more of said targets.

138. (Cancelled)

139. (Rejected) An apparatus according to claim 1, further comprising a sample stage being moveable to a plurality of processing positions inside said vacuum chamber under said continuous vacuum conditions for performing said removing, said plasma cleaning, said plasma etching and said coating of said specimen.

140. (Rejected) An apparatus according to claim 139, said sample stage being automatically moveable among said processing positions based on parameters set by a user.

141. (Rejected) An apparatus according to claim 140, said parameters including an order of movement among selected ones of said processing positions.

142. (Rejected) An apparatus according to claim 139, said sample stage being moveable in a first direction along a vertical axis of said vacuum chamber, said apparatus further comprising means for detecting a first position of a surface of said specimen along said vertical axis, wherein said sample stage is moved automatically to said plurality of processing positions based on said first position.

143. (Rejected) An apparatus according to claim 142, wherein said first position is measured relative to a second position along said vertical axis.

144. (Rejected) An apparatus according to claim 139, said sample stage being moveable in a first direction along a vertical axis of said vacuum chamber, said apparatus further comprising a beam generating device and a beam sensor supported by said vacuum chamber, said beam generating device and said beam sensor being used to detect a first position of a surface of said specimen along said vertical axis, wherein said sample stage is moved automatically to said plurality of processing positions based on said first

position.

145. (Rejected) An apparatus according to claim 144, wherein said first position is measured relative to a second portion along said vertical axis.

146. (Rejected) An apparatus according to claim 144, said beam generating device comprising a laser.

147. (Rejected)) An apparatus according to claim 139, said sample stage being moveable in a first direction along a vertical axis of said vacuum chamber, at least a first portion of said sample stage that supports said specimen being rotatable about said vertical axis, and at least a second portion of said sample stage connected to said first portion being moveable in a first angular direction with respect to said vertical axis.

148. (Rejected) An apparatus according to claim 147, at least a third portion of said sample stage connected to said second portion being moveable in a second angular direction with respect to said vertical axis.

149. (Previously Presented) An apparatus according to claim 139, said sample stage having at least three degrees of selective independent movement.

150. (Rejected) An apparatus according to claim 149, sample stage having at least four degrees of selective independent movement.

151. (Rejected)) An apparatus according to claim 1, said process chamber having a first aperture adjacent said plasma generator, a first moveable shutter for selectively covering said first aperture, a second aperture adjacent said means for plasma etching, and a second moveable shutter for selectively covering said second aperture.

152. (Withdrawn) A method for preparing a specimen for microscopy, comprising:

determining a first position of a surface of said specimen along an axis of a processing chamber;

automatically moving said specimen to one or more processing locations within said processing chamber based on said first position.

153. (Withdrawn) A method according to claim 152, said determining step further comprising determining said first position relative to a second position along said axis.

154. (Withdrawn) A method according to claim 152, said determining step further comprising:

generating a beam;

directing said beam at a sensor;

moving said specimen along said axis;

establishing said first position when a predetermined level is measured by said sensor.

155. (Withdrawn) A method according to claim 154, said beam comprising a laser beam.

156. (Withdrawn) A method according to claim 154, said predetermined level comprising approximately 50% of a level measured when said sensor is completely unobscured.

157. (Withdrawn) A method according to claim 156, said determining step further comprising:

(a) moving said specimen along said axis to an obscuring position in which said sensor is completely obscured and setting a blocked position variable equal to said obscuring position;

(b) moving said specimen along said axis to an unobscuring position in which said sensor is completely unobscured, obtaining an unobscured sensor level reading, and setting a clear position variable equal to said unobscuring position;

(c) moving said specimen to a midpoint position that is approximately halfway between a position equal to said blocked position variable and a position equal to said clear position variable;

(d) obtaining a current sensor level reading at said midpoint position;

(e) determining whether said current sensor level reading is equal to approximately 50% of said unobscured sensor level reading;

(f) setting said first position equal to said midpoint position if said current sensor level reading is equal to approximately 50% of said unobscured sensor level reading;

(g) setting said blocked position variable equal to said midpoint position if said current sensor level reading is less than approximately 50% of said unobscured sensor level reading and repeating steps (c) through (h) until said first position is set in step (f); and

(h) setting said clear position variable equal to said midpoint position if said current sensor level reading is greater than approximately 50% of said unobscured sensor level reading and repeating steps (c) through (h) until said first position is set in step (f).

158. (Rejected) An apparatus for preparing a specimen for microscopy, comprising:

a processing chamber;

a sample stage, said sample stage being moveable to one or more processing positions inside said processing chamber, said processing position being defined by three dimensional coordinates; and

means for detecting a first position of a surface of said specimen within said processing chamber;

wherein said sample stage is moved automatically to said one or more

processing positions remote from said first position in any of three dimensions and at an angle relative to a beam impinging thereon.

159. (Rejected) An apparatus according to claim 158, wherein said first position is measured relative to a second position along said axis.

160. (Rejected) An apparatus according to claim 158, said processing positions including positions for performing one or more of etching said specimen, plasma cleaning said specimen, plasma etching said specimen and coating said specimen with a conductive material.

161. (Rejected) An apparatus for preparing a specimen for microscopy, comprising:

a processing chamber;

a sample stage, said sample stage being moveable to one or more processing positions inside said processing chamber, said processing positions being defined by three dimensional coordinates; and

a beam generating device and a beam sensor supported by said processing chamber, said beam generating device and said beam sensor being used to detect a first position of a surface of said specimen within said processing chamber;

wherein said sample stage is moved automatically to said one or more processing positions remote from said first position in any of three dimensions and at an

angle relative to said beam generating device.

162. (Rejected) An apparatus according to claim 161, wherein said first position is measured relative to a second position along said axis.

163. (Rejected) An apparatus according to claim 161, said processing positions including positions for performing one or more of etching said specimen, plasma cleaning said specimen, plasma etching said specimen and coating said specimen with a conductive material.

164. (Rejected) An apparatus according to claim 161, said beam generating device comprising a laser.

APPENDIX OF EVIDENCE

The following is a list of the evidence entered in the record which Applicants rely upon in the appeal:

Exhibit A: Office Action dated May 6, 2010

Exhibit B: Applicant's response dated February 8, 2010

Exhibit C: United States Patent No. 4,858,556 to Siebert

Exhibit D: United States Patent No. 6,051,113 to Moslehi

Exhibit E: United States Patent No. 4,595,483 to Mahler

Exhibit F: United States Patent No. 6,325,857 to Miyoshi

Exhibit G: United States Patent No. 5,922,179 to Mitro

Exhibit H: United States Patent No. 6,419,802 to Baldwin

APPENDIX OF RELATED APPEALS AND INTERFERENCES

There are no related appeals or interferences.

EXHIBITS

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
10/633,130	08/01/2003	Paul E. Fischione	129/015	3089

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EXAMINER	
MCDONALD, RODNEY GLENN	
ART UNIT	**PAPER NUMBER**
1795	
MAIL DATE	**DELIVERY MODE**
05/06/2010	PAPER

Please find below and/or attached an Office communication concerning this application or proceeding.

The time period for reply, if any, is set in the attached communication.

Exhibit A

Office Action Summary	Application No.	Applicant(s)
	10/633,130	FISCHIONE ET AL.
	Examiner	Art Unit
	Rodney G. McDonald	1795

-- The MAILING DATE of this communication appears on the cover sheet with the correspondence address --

Period for Reply

A SHORTENED STATUTORY PERIOD FOR REPLY IS SET TO EXPIRE 3 MONTH(S) OR THIRTY (30) DAYS, WHICHEVER IS LONGER, FROM THE MAILING DATE OF THIS COMMUNICATION.

- Extensions of time may be available under the provisions of 37 CFR 1.136(a). In no event, however, may a reply be timely filed after SIX (6) MONTHS from the mailing date of this communication.
- If NO period for reply is specified above, the maximum statutory period will apply and will expire SIX (6) MONTHS from the mailing date of this communication.
- Failure to reply within the set or extended period for reply will, by statute, cause the application to become ABANDONED (35 U.S.C. § 133). Any reply received by the Office later than three months after the mailing date of this communication, even if timely filed, may reduce any earned patent term adjustment. See 37 CFR 1.704(b).

Status

1)☒ Responsive to communication(s) filed on *08 February 2010*.

2a)☒ This action is **FINAL**. 2b)☐ This action is non-final.

3)☐ Since this application is in condition for allowance except for formal matters, prosecution as to the merits is closed in accordance with the practice under *Ex parte Quayle*, 1935 C.D. 11, 453 O.G. 213.

Disposition of Claims

4)☒ Claim(s) *1,3-7,16-21,24-31,58-65,68,69,73-75,118,120,121 and 124-164* is/are pending in the application.

4a) Of the above claim(s) *152-157* is/are withdrawn from consideration.

5)☐ Claim(s) _____ is/are allowed.

6)☒ Claim(s) *1,3-7,16-21,24-31,58-65,68,69,73-75,118,120,121,124-135,137-151 and 158-164* is/are rejected.

7)☒ Claim(s) *136* is/are objected to.

8)☐ Claim(s) _____ are subject to restriction and/or election requirement.

Application Papers

9)☐ The specification is objected to by the Examiner.

10)☐ The drawing(s) filed on _____ is/are: a)☐ accepted or b)☐ objected to by the Examiner.

Applicant may not request that any objection to the drawing(s) be held in abeyance. See 37 CFR 1.85(a).

Replacement drawing sheet(s) including the correction is required if the drawing(s) is objected to. See 37 CFR 1.121(d).

11)☐ The oath or declaration is objected to by the Examiner. Note the attached Office Action or form PTO-152.

Priority under 35 U.S.C. § 119

12)☐ Acknowledgment is made of a claim for foreign priority under 35 U.S.C. § 119(a)-(d) or (f).

a)☐ All b)☐ Some * c)☐ None of:

1.☐ Certified copies of the priority documents have been received.

2.☐ Certified copies of the priority documents have been received in Application No. _____.

3.☐ Copies of the certified copies of the priority documents have been received in this National Stage application from the International Bureau (PCT Rule 17.2(a)).

* See the attached detailed Office action for a list of the certified copies not received.

Attachment(s)

1)☐ Notice of References Cited (PTO-892)

2)☐ Notice of Draftsperson's Patent Drawing Review (PTO-948)

3)☐ Information Disclosure Statement(s) (PTO/SB/08) Paper No(s)/Mail Date _____.

4)☐ Interview Summary (PTO-413) Paper No(s)/Mail Date. _____.

5)☐ Notice of Informal Patent Application

6)☐ Other: _____.

DETAILED ACTION

Election/Restrictions

This application contains claims 152-157 drawn to an invention nonelected. A complete reply to the final rejection must include cancellation of nonelected claims or other appropriate action (37 CFR 1.144) See MPEP § 821.01.

Claim Rejections - 35 USC § 112

The following is a quotation of the first paragraph of 35 U.S.C. 112:

> The specification shall contain a written description of the invention, and of the manner and process of making and using it, in such full, clear, concise, and exact terms as to enable any person skilled in the art to which it pertains, or with which it is most nearly connected, to make and use the same and shall set forth the best mode contemplated by the inventor of carrying out his invention.

Claims 1, 3-7, 16-21, 24-31, 58-65, 68, 69, 73-75, 118, 120, 121, 124-137 and 139-151 are rejected under 35 U.S.C. 112, first paragraph, as failing to comply with the written description requirement. The claim(s) contains subject matter which was not described in the specification in such a way as to reasonably convey to one skilled in the relevant art that the inventor(s), at the time the application was filed, had possession of the claimed invention. Specifically it is unclear where there is support for selective spatial isolation of said means for plasma etching said specimen and said specimen from said plasma generator, said means for removing material and said means for coating said specimen when said means for plasma etching said specimen is operational. What element isolates the means for etching from each of the devices?

Claim Rejections - 35 USC § 103

The following is a quotation of 35 U.S.C. 103(a) which forms the basis for all obviousness rejections set forth in this Office action:

> (a) A patent may not be obtained though the invention is not identically disclosed or described as set forth in section 102 of this title, if the differences between the subject matter sought to be patented and the prior art are such that the subject matter as a whole would have been obvious at the time the invention was made to a person having ordinary skill in the art to which said subject matter pertains. Patentability shall not be negatived by the manner in which the invention was made.

This application currently names joint inventors. In considering patentability of the claims under 35 U.S.C. 103(a), the examiner presumes that the subject matter of the various claims was commonly owned at the time any inventions covered therein were made absent any evidence to the contrary. Applicant is advised of the obligation under 37 CFR 1.56 to point out the inventor and invention dates of each claim that was not commonly owned at the time a later invention was made in order for the examiner to consider the applicability of 35 U.S.C. 103(c) and potential 35 U.S.C. 102(e), (f) or (g) prior art under 35 U.S.C. 103(a).

Claims 1, 3-7, 21, 24, 25, 58-64, 68, 69, 73, 74, 121, 124, 129, 139, 140, 141, 142, 143, 149 and 151 are rejected under 35 U.S.C. 103(a) as being unpatentable over Siebert (U.S. Pat. 4,858,556) in view of Moslehi (U.S. Pat. 6,051,113), Mahler (U.S. Pat. 4,595,483) and Miyoshi (U.S. Pat. 6,325,857).

Regarding claim 1, Siebert teach an apparatus including means for removal of material from the specimen. (Column 12 lines 59-64; Column 12 line 28) Means for coating the specimen. (Column 12 lines 52-56) Also any of a number of different types

of sources can be provided in the apparatus. (Column 12 lines 24-25) The processes can be carried out in a single process chamber 10 (Figs. 6 and 7) under continuous vacuum conditions. (Column 9 lines 49-58)

Regarding claim 3, the means for removing comprises a means for etching using an ion beam. (Column 12 line 28; Column 12 lines 59-64)

Regarding claims 4, Siebert teach that the means for etching comprises an ion beam source for directing an ion beam at the specimen. (Column 22 lines 19-22)

Regarding claims 5, a source of process gas is inherently positioned adjacent the ion source in order to produce the ion beam. (Column 22 lines 18-22)

Regarding claim 6, Siebert teach utilizing a magnetron sputtering device. (Column 12 line 26)

Regarding claim 7, Siebert teach as the source an ion source for directing an ion beam at a target can be used. (Column 12 lines 64-68; Column 13 lines 1-3)

Regarding claim 21, Siebert teach a vacuum pump connected to the process chamber to evacuate the chamber to a selected vacuum level. (Column 9 lines 58-62)

Regarding claim 68, Siebert suggest ion etching under continuous vacuum conditions. (Column 22 lines 9-22)

Regarding claim 69, Siebert teach an ion beam for etching. (Column 22 lines 9-22)

Regarding claim 73, Siebert teach utilizing a shutter to selectively expose the specimen to ion beam etching. (Column 11 lines 31-43)

Regarding claim 74, Siebert teach a specimen stage for moving the specimen inside and outside of the ion beam. (Column 10 lines 56-60)

Regarding claim 124, Siebert teach controlling the powers to sources. (Column 13 lines 39-68)

Regarding claim 129, Siebert teach ion beam sputtering coating utilizing a target an ion beam. (Column 13 lines 1-3)

Regarding claim 139, Siebert teach a sample stage being movable to a plurality of processing positions in the vacuum chamber under continuous vacuum conditions for performing processes. (Figs. 6, 7 item 16)

Regarding claims 140, 141, Siebert teach automatic control for the moving the substrate. (Column 13 lines 39-68; Column 14 lines 1-68; Column 15 lines 1-68)

Regarding claims 142, 143, Siebert teach adjusting the source to substrate distance vertically. (Column 10 lines 52-56; Column 6 lines 18-22)

Regarding claim 149, Siebert teach at least three degrees of movement. (i.e. source to substrate distance, rotational movement and orbital motion) (Column 10 lines 52-56; Column 14 lines 1-2)

Regarding claim 151, Siebert teach utilizing shutters. (Column 11 lines 31-43)

The differences between Siebert and the present claims is that the plasma generator for plasma cleaning the specimen is not discussed (Claim 1), coating the specimen with conductive material is not discussed (Claim 1), means for plasma etching is not discussed (Claim 1), utilizing an oil free vacuum pump is not discussed (Claim 24), utilizing a particular kind of pump is not discussed (Claim 25), the plasma etching

being capacitive discharge plasma etching is not discussed (Claim 58), the means for plasma etching comprising a first electrode supported by said process chamber and a second electrode supported by said process chamber, said first and second electrodes defining a gap therebetween for receiving said specimen is not discussed (Claim 59), the first and second electrodes each comprising a substantially planar electrode, said first electrode and said second electrode being substantially parallel to one another is not discussed (Claim 60), the specimen stage for holding said specimen, said specimen stage being supported by said process chamber, at least a portion of said specimen stage being said first electrode is not discussed (Claim 61), the specimen stage being moveable in a direction substantially perpendicular to a planar surface of said first electrode is not discussed (Claim 62), the second electrode being moveable in a direction substantially perpendicular to a planar surface of said second electrode is not discussed (Claim 63), the alternating voltage source connected to said first and second electrodes for generating an electric field within said gap, said electric field generating a plasma from a gas introduced into said gap is not discussed (Claim 64) and means for selective spatial isolation of the other means when the plasma etching means is in operation is not discussed (Claim 1).

Regarding the plasma generator for plasma cleaning the specimen (Claim 1), Siebert discussed above already teach that any source may be provided in the apparatus including multiple sources. (See Siebert Column 12 lines 24-25) Moslehi teach an apparatus including a plasma generator for plasma cleaning the specimen. (Column 10 lines 27-28) The plasma cleaning and the coating of the specimen can be

performed in a single process chamber under continuous vacuum conditions. (Fig. 2; Column 8 lines 53-54)

Regarding coating the specimen with conductive material (Claim 1), Moslehi teach an apparatus including a plasma generator for plasma cleaning the specimen. (Column 10 lines 27-28) The apparatus can include means for coating a specimen with conductive material. (Column 10 lines 25-27) The plasma cleaning and the coating of the specimen can be performed in a single process chamber under continuous vacuum conditions. (Fig. 2; Column 8 lines 53-54)

Regarding claim 24, Moslehi teach utilizing an oil-free vacuum pump. (Column 8 lines 54-57)

Regarding claims 25, Moslehi teach utilizing a cryosorption vacuum pump. (Column 8 lines 54-57)

The motivation for utilizing the features of Moslehi is that it allows for performing operations in a single chamber. (Column 8 lines 53-54)

Regarding the means for plasma etching (Claim 1), Siebert discussed above already teach that any source may be provided in the apparatus including multiple sources. (See Siebert Column 12 lines 24-25) Mahler teach an apparatus including means for coating a specimen with a material from a sputtering coating source and means for plasma etching the specimen. (Column 4 lines 1-10) The coating of the specimen and the plasma etching of the specimen occurs in a single vacuum chamber 4 evacuated by pump 29. (Column 4 lines 1-10; Column 5 lines 11-13)

Regarding claim 58, 121, Mahler teach the plasma etching is capacitive discharge plasma etching. (Column 2 lines 61-68; Column 3 lines 1-3)

Regarding claim 59, the substrate holder and the charging cover represent the first and second electrodes with the specimen in between. (Column 2 lines 61-68; Column 3 lines 1-3)

Regarding claim 60, Mahler teach the first and second electrodes are substantially planar and are parallel to one another. (Column 2 lines 61-68; Column 3 lines 1-3)

Regarding claim 61, Mahler teach a specimen stage 26 for holding the substrate and being part of the first electrode is present. (Column 4 lines 53-56)

Regarding claim 63, Mahler teach the second electrode cover can move the in a direction perpendicular by a lift device. (Column 4 lines 7-10)

Regarding claim 64, 121, Mahler teach utilizing an alternating voltage source for generating the plasma. (Column 2 lines 63)

The motivation for utilizing the features of Mahler is that it allows for performing processes in a single chamber. (Column 4 lines 1-10; Column 5 lines 11-13)

Regarding isolating the etching means form the other means (claim 1), Miyoshi teach a shutter which isolates means from an etching means. (Column 9 lines 62-68; Column 10 lines 1-4)

The motivation for utilizing the features of Miyoshi is that it allows for protecting the other means in the chamber to be effected by the etching. (Column 10 lines 16-17)

Therefore, it would have been obvious to one of ordinary skill in the art at the time the invention was made to have modified Siebert by utilizing the features of Moslehi, Mahler and Miyoshi because it allows for performing process in a single chamber and protecting the other means from the etching device.

Claims 16, 65 are rejected under 35 U.S.C. 103(a) as being unpatentable over Siebert in view of Moslehi, Mahler and Miyoshi as applied to claims 1, 3-7, 21, 24, 25, 58-64, 68, 69, 73, 74, 121, 124, 129, 139, 140, 141, 142, 143, 149 and 151 above, and further in view of Ameen et al. (U.S. Pat. 6,143,128).

The differences not yet discussed are that the plasma generator is not discussed. (Claim 16) and the use of an inductively coupled plasma is not discussed (claim 65).

Regarding claim 16, Ameen et al. teach that for cleaning a RF coil for a chamber can be utilized. (Column 9 lines 48-68; Column 10 lines 1-7)

Regarding claims 65, Ameen et al. teach that for cleaning a RF coil for a chamber can be utilized. (Column 9 lines 48-68; Column 10 lines 1-7)

The motivation for utilizing an RF coil for cleaning is that it allows for cleaning the substrate. (Column 9 lines 48-68; Column 10 lines 1-7)

Therefore, it would have been obvious to one of ordinary skill in the art at the time the invention was made to have utilized a plasma generator as taught by Ameen et al. because it allows for cleaning of the substrate.

Claims 17-20 are rejected under 35 U.S.C. 103(a) as being unpatentable over Siebert in view of Moslehi, Mahler and Miyoshi in view of Ameen et al. as applied to

claim 1, 3-7, 21, 24, 25, 58-64, 68, 69, 73, 74, 121, 124, 129, 139, 140, 141, 142, 143, 149 and 151 above, and further in view of Chang et al. (U.S. Pat. 6,434,814).

The differences not yet discussed is the gases used for cleaning and multiple gas inlets and magnetron sputtering

Regarding claims 17, 18, 19, 20, Chang et al. teach that Ar and oxygen can be utilized for clean etching. Utilizing two gases would require two inlets for the gases. (Column 8 lines 57-65)

Chang et al. suggests magnetron coating for sputtering. (Column 6 lines 57-62)

The motivation for utilizing Ar and oxygen is that it allows for cleaning. (Column 8 lines 57-65)

Therefore, it would have been obvious to one of ordinary skill in the art at the time the invention was made to have utilized oxygen and argon as taught by Chang et al. because it allows cleaning of the substrate.

Claims 26-29, 75, 147, 148, 150 are rejected under 35 U.S.C. 103(a) as being unpatentable over Siebert in view of Moslehi, Mahler and Miyoshi as applied to claims 1, 3-7, 21, 24, 25, 58-64, 68, 69, 73, 74, 121, 124, 129, 139, 140, 141, 142, 143, 149 and 151 above, and further in view of Mitro et al. (U.S. Pat. 5,922,179).

The differences not yet discussed are the rotating and tilting of the substrate (Claims 26, 28, 29, 75), the cooling of the substrate (Claim 27), moving the substrate in a first angular direction (Claim 147), moving the substrate in a second angular direction (Claim 148) and four degrees of movement is not discussed (Claim 150).

Regarding claims 26, 29, 75, Mitro et al. teach a specimen holder that rotates and rocks. (Column 4 lines 20-27)

Regarding claim 27, Mitro et al. teach a specimen holder that is cooled. (Column 3 lines 15-22)

Regarding claim 147, Siebert discussed above teaching moving the stage in a vertical direction to control distance between the target and the substrate. The substrate can be rotated. (See Seibert discussed above) Mitro et al. teach rocking the substrate holder which means the substrate holder is moved in first and second angular directions. (Mitro et al. Column 4 lines 20-27)

Regarding claim 150, Siebert discussed above already teach three degrees of movement. (See Siebert discussed above) Mitro et al. teach a fourth degree of movement (i.e. rocking). (See Mitro et al. discussed above)

The motivation for cooling, rotating and tilting the substrate is that it allows for uniform coating and etching of the film. (Column 4 lines 20-33)

Regarding claims 28, 29, 75, Moslehi suggest the stage being movable up and down along an axis. (See Moslehi Fig. 2)

Therefore, it would have been obvious to one of ordinary skill in the art at the time the invention was made to have cooled, rotated and tilted the substrate holder as taught by Mitro et al. because it allows for uniform coating and etching of the film.

Claim 30 is rejected under 35 U.S.C. 103(a) as being unpatentable over Siebert in view of Moslehi, Mahler and Miyoshi as applied to claims 1, 3-7, 21, 24, 25, 58-64,

68, 69, 73, 74, 121, 124, 129, 139, 140, 141, 142, 143, 149 and 151 above, and further in view of Kobayashi et al. (U.S. Pat. 5,340,460).

The difference not yet discussed is the use of a cold trap.

Kobayashi et al. teach a cold trap in the chamber. (Column 4 lines 32-39; Fig. 3)

The motivation for providing a cold trap in the chamber is that it allows for capturing residual gases. (See Abstract)

Therefore, it would have been obvious to one of ordinary skill in the art at the time the invention was made to have utilized a cold trap as taught by Kobayashi et al. because it traps residual gases.

Claim 31 is rejected under 35 U.S.C. 103(a) as being unpatentable over Siebert in view of Moslehi, Mahler and Miyoshi as applied to claims 1, 3-7, 21, 24, 25, 58-64, 68, 69, 73, 74, 121, 124, 129, 139, 140, 141, 142, 143, 149 and 151 above, and further in view of Holland (U.S. Pat. 4,311,725).

The difference not yet discussed is the crystal oscillator.

Holland teach a crystal oscillator for measuring the amount of total material deposited and ending deposition. (Column 8 lines 11-40)

The motivation for utilizing a crystal oscillator is that it allows for measuring the amount of film deposited. (Column 8 lines 11-40)

Therefore, it would have been obvious to one of ordinary skill in the art at the time the invention was made to have utilized a crystal oscillator as taught by Holland because it allows for measuring the thickness.

Claim 118 is rejected under 35 U.S.C. 103(a) as being unpatentable over Siebert in view of Moslehi, Mahler and Miyoshi as applied to claims 1, 3-7, 21, 24, 25, 58-64, 68, 69, 73, 74, 121, 124, 129, 139, 140, 141, 142, 143, 149 and 151 above, and further in view of Nomura et al. (U.S. Pat. 6,641,703).

The difference not yet discussed is the use of a load lock. (Claim 118)

Regarding claim 118, Nomura et al. teach the load/unload chamber. (Column 6 lines 22-25)

The motivation for utilizing load lock chamber is for loading of the substrate. (Column 6 lines 22-25)

Therefore, it would have been obvious to one of ordinary skill in the art at the time the invention was made to have utilizing a load lock as taught by Nomura et al. because it allows for loading the substrate.

Claims 120 and 125-128 are rejected under 35 U.S.C. 103(a) as being unpatentable over Siebert in view of Moslehi, Mahler and Miyoshi as applied to claims 1, 3-7, 21, 24, 25, 58-64, 68, 69, 73, 74, 121, 124, 129, 139, 140, 141, 142, 143, 149 and 151 above, and further in view of Chang et al. (U.S. Pat. 6,434,814).

The differences not yet discussed are the reactive gas (Claim 120), the two gas inlets (claims 125, 127) and the process gas being oxygen (Claims 126, 128).

Regarding claims 120, 125, 126, 127, 128, Chang et al. teach that Ar and oxygen can be utilized for clean etching. Utilizing two gases would require two inlets for the gases. (Column 8 lines 57-65)

The motivation for utilizing the features of Chang et al. is that it allows for cleaning. (See Chang et al. discussed above)

Therefore, it would have been obvious to one of ordinary skill in the art at the time the invention was made to have utilized the features of Chang et al. because it allows for cleaning.

Claims 130-135 and 137 are rejected under 35 U.S.C. 103(a) as being unpatentable over Siebert in view of Moslehi, Mahler and Miyoshi as applied to claims 1, 3-7, 21, 24, 25, 58-64, 68, 69, 73, 74, 121, 124, 129, 139, 140, 141, 142, 143, 149 and 151 above, and further in view of Hurwitt (U.S. Pat. 3,756,939).

The difference not yet discussed is a lever supported by said vacuum chamber, said lever holding said target, said lever being selectively moveable into a position in which said ion beam is directed at said target is not discussed (Claim 130), the means for coating comprising a plurality of targets, each of said targets being formed of a conductive material, said ion source directing said ion beam at a selected one of said targets is not discussed (Claim 131), the means for moving said selected one of said targets from a covered position to an exposed position is not discussed (Claim 132), the lever supported by said vacuum chamber, said lever holding said plurality of targets, said lever being selectively moveable into a position in which said ion beam is directed at said selected one of said targets is not discussed (Claim 133) the plurality of targets being held by a target holder, said target holder being moveable among a plurality of positions, each of said positions exposing one of said targets and covering a remaining one or more of said targets is not discussed (Claim 134), the target holder being

rotatably supported by said lever, said target holder being rotatable among said plurality of positions is not discussed (Claim 135), the means for selectively exposing said selected one of said targets and covering a remaining one or more of said targets is not discussed (Claim 137).

Regarding claims 130-135, 137, Hurwitt teach a lever holding a target and selectively movable into a position in which a target is exposed to be sputtered. Targets can be covered while one is exposed to be sputtered. (Column 4 lines 3-39)

The motivation for utilizing Hurwitt is that it allows for sputtering from a number of targets in sequence. (See Abstract)

Therefore, it would have been obvious to one of ordinary skill in the art at the time the invention was made to have utilized the features of Hurwitt because it allows for sputtering from a number of targets in sequence.

Claims 144-146 are rejected under 35 U.S.C. 103(a) as being unpatentable over Siebert in view of Moslehi, Mahler and Miyoshi as applied to claims 1, 3-7, 21, 24, 25, 58-64, 68, 69, 73, 74, 121, 124, 129, 139, 140, 141, 142, 143, 149 and 151 above, and further in view of Baldwin et al. (U.S. Pat. 6,419,802).

The differences not yet discussed is utilizing a beam sensor to sense the position of the substrate (Claim 144), detecting the first position relative to a second position along the vertical axis (Claim 145), and where the beam is a laser (Claim 146).

Regarding claims 144-146, Siebert teach adjusting the source to substrate distance vertically. (Column 10 lines 52-56; Column 6 lines 18-22) Siebert teach a motion mechanism is utilized for positioning the substrates. (Column 6 lines 18-22)

Baldwin et al. teach utilizing a beam (i.e. laser) for sensing the position of the substrate. (Column 4 lines 17-44)

The motivation for utilizing a sensor is that it determines the position of the substrate. (Column 4 lines 17-44)

Therefore, it would have been obvious to one of ordinary skill in the art at the time the invention was made to have utilized the features of Baldwin et al. because it allows for determining the position of the substrate.

Claims 158-160 are rejected under 35 U.S.C. 103(a) as being unpatentable over Moslehi (U.S. Pat. 6,051,113) in view of Mitro et al. (U.S. Pat. 5,922,179) and Baldwin et al. (U.S. Pat. 6,419,802).

Regarding claim 158, Moslehi teach a processing chamber including a sample stage being moveable to one or more positions in the processing chamber. Moslehi teach a position sensor for detecting a position of the specimen. The sample stage can be moved automatically to one or more processing positions remote form the first position in any of the three dimensions. (Fig. 2; Column 10 lines 25-28; Column 8 lines 53-54; Column 4 lines 17-44)

Regarding claim 159, the first position is measured relative to a second position along an axis. (Column 4 lines 17-44)

Regarding claim 160, the processing position can be one of coating or cleaning. (Column 10 lines 25-28)

The difference between Moslehi and the present claims is that holding the substrate at an angle relative to a beam impinging thereon.

Mitro discussed above teach rocking the substrate and thus disposing the substrate at an angle. (See Mitro discussed above)

Baldwin et al. teach utilizing a beam to detect position. (See Baldwin et al. discussed above)

The motivation for utilizing the features of Mitro is that it allows for uniform coating and etching of the film. (Mitro Column 4 lines 20-33)

The motivation for utilizing the features of Baldwin et al. is that it allows for utilizing a sensor is that it determines the position of the substrate. (Baldwin et al. Column 4 lines 17-44)

Therefore, it would have been obvious to one of ordinary skill in the art at the time the invention was made to have modified Moslehi by utilizing the features of Mitro and Baldwin et al. because it allows for uniform coating and etching of the film and for determining the position of the substrate.

Claims 161, 162, 163, 164 are rejected under 35 U.S.C. 103(a) as being unpatentable over Moslehi (U.S. Pat. 6,051,113) in view of Baldwin et al. (U.S. Pat. 6,419,802) and Mitro et al. (U.S. Pat. 5,922,179).

Regarding claim 161, Moslehi teach a processing chamber including a sample stage being moveable to one or more positions in the processing chamber. Moslehi teach a position sensor for detecting a position of the specimen. The sample stage can be moved automatically to one or more processing positions remote form the first position in any of the three dimensions. (Fig. 2; Column 10 lines 25-28; Column 8 lines 53-54; Column 4 lines 17-44)

Regarding claim 162, the first position is measured relative to a second position along an axis. (Column 4 lines 17-44)

Regarding claim 163, the processing position can be one of coating or cleaning. (Column 10 lines 25-28)

The differences between Moslehi and the present claims is that the use of a beam such as a laser is not discussed (claims 161, 164) and holding the substrate at an angle (Claim 161).

Regarding claims 161, 164, Baldwin et al. teach utilizing a beam (i.e. laser) for sensing the position of the substrate. (Column 4 lines 17-44)

The motivation for utilizing a sensor is that it determines the position of the substrate. (Column 4 lines 17-44)

Regarding claim 161, Mitro teach holding the substrate at an angle. (See Mitro et al. discussed above)

The motivation for utilizing the feature of Mitro is that t allows for uniform coating and etching of the film. (Column 4 lines 20-33)

Therefore, it would have been obvious to one of ordinary skill in the art at the time the invention was made to have modified Moslehi by utilizing a position sensor and laser as taught by Baldwin et al. because it allows for determining the position of the substrate.

Allowable Subject Matter

Claim 136 is objected to as being dependent upon a rejected base claim, but would be allowable if rewritten in independent form including all of the limitations of the base claim and any intervening claims.

The following is a statement of reasons for the indication of allowable subject matter:

Claim 136 is indicated as being allowable because the prior art of record does not teach the target holder including a plurality of pins, the vacuum chamber supporting an arm, the target holder being selectively rotated by contact between the arm and any one of the pins.

Response to Arguments

Applicant's arguments filed July 6, 2009 have been fully considered but they are not persuasive.

Response to the arguments of the 35 U.S.C. 112 1st paragraph rejections:

In response to the argument that Applicant provides sufficient written description to show the means responsible for isolating the means for etching from the other devices, it is argued that the specification does not support isolating the means for plasma etching from the space (i.e. spatial isolation). Instead the specification discusses how the other devices are isolated from the space but not how the means for etching is isolated from the space. The Examiner interprets "spatial isolation" as isolating the means for etching from the space.

The Examiner withdraws the 35 U.S.C. 112 1st paragraph rejection in regards to utilizing a single process chamber for carrying out the plasma cleaning and coating of the specimen based in Applicant's argument.

Response to the arguments of the 35 U.S.C. 103 rejection:

In response to the argument that the prior art does not teach the plasma etching device to be isolated from the other component functionalities of the device when the means for plasma etching the specimen is operational, it is argued that Siebert et al. do teach utilizing a shutter to expose the specimen to appropriate hardware. Miyoshi teach utilizing a shutter to close off the means from one another so that the different process do not affect the functionalities of the other components. The shutter spatially separates the devices from one another. One of ordinary skill in the art would readily envisage incorporating shutter means to isolate each of the devices of Siebert et al. because Miyoshi suggest that it is necessary to prevent the devices from affecting one another. (See Miyoshi and Siebert discussed above)

In response to the argument that a shutter does not spatially separate the specimen and plasma etching mechanism from the other operative components, it is argued that Siebert et al. do teach utilizing a shutter to expose the specimen to appropriate hardware. . Miyoshi teach utilizing a shutter to close off the means from one another so that the different process do not affect the functionalities of the other components. The shutter spatially separates the devices from one another. One of ordinary skill in the art would readily envisage incorporating shutter means to isolate each of the devices of Siebert et al. because Miyoshi suggest that it is necessary to

prevent the devices from affecting one another. Furthermore Applicant remarks that a shutter covering a sputter deposition device will spatially isolate the devices from one another. Since both Siebert and Miyoshi teach utilizing shutters to isolate devices and since Applicant utilizes shutters for spatial isolation a shutter as a means for spatial isolation would have been obvious. (See Miyoshi and Siebert discussed above)

In response to the argument that Miyoshi does not teach shielding specimen or other fixtures in the chamber, it is argued that Miyoshi teach utilizing a shutter to close off the means from one another so that the different process do not effect the functionalities of the other components. The shutter spatially separates the devices from one another. One of ordinary skill in the art would readily envisage incorporating shutter means to isolate each of the devices of Siebert et al. because Miyoshi suggest that it is necessary to prevent the devices from affecting one another. (See Miyoshi and Siebert discussed above)

In response to applicant's argument that the examiner's conclusion of obviousness is based upon improper hindsight reasoning, it must be recognized that any judgment on obviousness is in a sense necessarily a reconstruction based upon hindsight reasoning. But so long as it takes into account only knowledge which was within the level of ordinary skill at the time the claimed invention was made, and does not include knowledge gleaned only from the applicant's disclosure, such a reconstruction is proper. See *In re McLaughlin*, 443 F.2d 1392, 170 USPQ 209 (CCPA 1971).

Conclusion

THIS ACTION IS MADE FINAL. Applicant is reminded of the extension of time policy as set forth in 37 CFR 1.136(a).

A shortened statutory period for reply to this final action is set to expire THREE MONTHS from the mailing date of this action. In the event a first reply is filed within TWO MONTHS of the mailing date of this final action and the advisory action is not mailed until after the end of the THREE-MONTH shortened statutory period, then the shortened statutory period will expire on the date the advisory action is mailed, and any extension fee pursuant to 37 CFR 1.136(a) will be calculated from the mailing date of the advisory action. In no event, however, will the statutory period for reply expire later than SIX MONTHS from the mailing date of this final action.

Any inquiry concerning this communication or earlier communications from the examiner should be directed to Rodney G. McDonald whose telephone number is 571-272-1340. The examiner can normally be reached on M-Th with every Friday off.

If attempts to reach the examiner by telephone are unsuccessful, the examiner's supervisor, Nam X. Nguyen can be reached on 571-272-1342. The fax phone number for the organization where this application or proceeding is assigned is 571-273-8300.

Information regarding the status of an application may be obtained from the Patent Application Information Retrieval (PAIR) system. Status information for published applications may be obtained from either Private PAIR or Public PAIR. Status information for unpublished applications is available through Private PAIR only. For more information about the PAIR system, see http://pair-direct.uspto.gov. Should you have questions on access to the Private PAIR system, contact the Electronic Business Center (EBC) at 866-217-9197 (toll-free). If you would like assistance from a USPTO Customer Service Representative or access to the automated information system, call 800-786-9199 (IN USA OR CANADA) or 571-272-1000.

/Rodney G. McDonald/
Primary Examiner, Art Unit 1795

Rodney G. McDonald
Primary Examiner
Art Unit 1795

RM
May 4, 2010

Attorney Docket No. 129/015

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Group Art Unit 1753	:	PATENT APPLICATION
Examiner R. McDonald	:	
In re application of	:	**METHOD AND APPARATUS FOR PREPARING SPECIMENS FOR MICROSCOPY**
FISCHIONE ET AL.	:	
Serial No.: 10/633,130	:	
Filed: August 1, 2003	:	

RESPONSE TO OFFICE ACTION

Pittsburgh, Pennsylvania 15222

February 8, 2010

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

In response to the Office Action dated November 6, 2009, Applicants submit the following amendments and remarks.

A Listing of the Claims begins on page 2 of this paper.

Remarks begin on page 20 of this paper.

Exhibit B

THE CLAIMS

1. (Previously Presented) An apparatus for preparing a specimen for microscopy, comprising:

a plasma generator for plasma cleaning said specimen;

means for removing material from said specimen;

means for coating said specimen with a conductive material; and

means for plasma etching said specimen which includes the selective spatial isolation of said means for plasma etching said specimen and said specimen from said plasma generator, said means for removing material and said means for coating said specimen when said means for plasma etching said specimen is operational;

wherein said plasma cleaning of said specimen and said coating of said specimen may be performed in a single process chamber under continuous vacuum conditions.

2. (Cancelled)

3. (Previously Presented) An apparatus according to claim 1, wherein said means for removing comprises means for etching said specimen using an ion beam.

4. (Original) An apparatus according to claim 3, wherein said means for etching comprises an ion source for directing said ion beam at said specimen.

5. (Original) An apparatus according to claim 4, wherein said means for etching further comprises a source of process gas positioned adjacent said ion source.

6. (Original) An apparatus according to claim 1, said means for coating comprising a magnetron sputtering device.

7. (Original) An apparatus according to claim 1, said means for coating comprising an ion source for directing an ion beam at a target, said target being formed of said conductive material.

8. (Cancelled)

9. (Cancelled)

10. (Cancelled)

11. (Cancelled)

12. (Cancelled)

13. (Cancelled)

14. (Cancelled)

15. (Cancelled)

16. (Original) An apparatus according to claim 1, wherein said plasma generator comprises a plasma tube, a coil wrapped around said plasma tube, and an RF power supply connected to said coil.

17. (Original) An apparatus according to claim 16, further comprising a source of process gas including oxygen connected to said plasma tube, said plasma cleaning being performed using said process gas.

18. (Original) An apparatus according to claim 17, said process gas further including argon.

19. (Original) An apparatus according to claim 18, said process gas comprising a mixture of 75% argon and 25% oxygen.

20. (Original) An apparatus according to claim 17, said process gas further including a non-reactive gas.

21. (Previously Presented) An apparatus according to claim 1, further comprising a vacuum pump connected to said process chamber for evacuating said process chamber to a selected vacuum level.

22. (Cancelled)

23. (Cancelled)

24. (Previously Presented) An apparatus according to claim 21, further comprising an oil-free vacuum pump for controlling said vacuum conditions.

25. (Previously Presented) An apparatus according to claim 24, said oil-free vacuum pump selected from the group consisting of oil-free diaphragm pumps, molecular drag pumps, turbomolecular drag pumps, molecular drag pumps backed by a diaphragm pump, turbomolecular drag pumps backed by a diaphragm pump, cryosorption pumps, reciprocating piston pumps, scroll pumps, screw pumps, claw pumps, non-oil sealed single and multistage piston pumps, and rotary lobe pumps.

26. (Previously Presented) An apparatus according to claim 1, further comprising a specimen stage for holding said specimen, said specimen stage being adapted to tilt said specimen with respect to said means for removing, said specimen stage being rotatable about an axis of rotation generally perpendicular to a plane defined by a surface of said specimen when said specimen is held by said specimen stage.

27. (Original) An apparatus according to claim 26, further comprising means for cooling said specimen stage.

28. (Original) An apparatus according to claim 26, said specimen stage being selectively moveable along said axis of rotation.

29. (Previously Presented) An apparatus according to claim 1, said chamber further comprising a specimen stage for holding said specimen, said specimen stage being adapted to tilt said specimen with respect to said means for removing, said specimen stage being rotatable about an axis of rotation generally perpendicular to a plane defined by a surface of said specimen when

said specimen is held by said specimen stage.

30. (Previously Presented) An apparatus according to claim 1, said chamber further comprising a cold trap.

31. (Previously Presented) An apparatus according to claim 1, said chamber further comprising a crystal oscillator for measuring an amount of said conductive material that is deposited on said specimen.

32. (Cancelled)

33. (Cancelled)

34. (Cancelled)

35. (Cancelled)

36. (Cancelled)

37. (Cancelled)

38. (Cancelled)

39. (Cancelled)

40. (Cancelled)

41. (Cancelled)

42. (Cancelled)

43. (Cancelled)

44. (Cancelled)

45. (Cancelled)

46. (Cancelled)

47. (Cancelled)

48. (Cancelled)

49. (Cancelled)

50. (Cancelled)

51. (Cancelled)

52. (Cancelled)

53. (Cancelled)

54. (Cancelled)

55. (Cancelled)

56. (Cancelled)

57. (Cancelled)

58. (Previously Presented) An apparatus according to claim 1, said plasma etching further comprising capacitive discharge plasma etching.

59. (Previously Presented) An apparatus according to claim 58, said means for plasma etching comprising a first electrode supported by said process chamber and a second electrode supported by said process chamber, said first and second electrodes defining a gap therebetween for receiving said specimen.

60. (Original) An apparatus according to claim 59, said first and second electrodes each comprising a substantially planar electrode, said first electrode and said second electrode being

substantially parallel to one another.

61. (Previously Presented) An apparatus according to claim 60, further comprising a specimen stage for holding said specimen, said specimen stage being supported by said process chamber, at least a portion of said specimen stage being said first electrode.

62. (Original) An apparatus according to claim 61, said specimen stage being moveable in a direction substantially perpendicular to a planar surface of said first electrode.

63. (Original) An apparatus according to claim 61, said second electrode being moveable in a direction substantially perpendicular to a planar surface of said second electrode.

64. (Original) An apparatus according to claim 59, further comprising an alternating voltage source connected to said first and second electrodes for generating an electric field within said gap, said electric field generating a plasma from a gas introduced into said gap.

65. (Previously Presented) An apparatus according to claim 1, said plasma etching further comprising inductively coupled plasma etching.

66. (Cancelled)

67. (Cancelled)

68. (Previously Presented) An apparatus according to claim 3, further comprising means for ion beam etching said specimen, wherein said ion beam etching may be performed under said continuous vacuum conditions.

69. (Previously Presented) An apparatus according to claim 68, further comprising an ion source for directing an ion beam at said specimen, said ion beam etching said specimen, wherein said etching of said specimen with said ion beam may be performed under continuous vacuum conditions.

70. (Cancelled)

71. (Cancelled)

72. (Cancelled)

73. (Previously Presented) An apparatus according to claim 69, wherein said ion source may selectively direct said ion beam at said specimen for ion beam etching said specimen under said continuous vacuum conditions.

74. (Original) An apparatus according to claim 73, further comprising a specimen stage for holding said specimen, said specimen stage being moveable between a first position in which said specimen is within a path of said ion beam such that said ion beam is directed at and impinges upon said specimen and a second position in which said specimen is outside of said path such that said ion beam is directed at and impinges upon said target.

75. (Previously Presented) An apparatus according to claim 74, said specimen stage being adapted to tilt said specimen with respect to said ion source, said specimen stage being rotatable about an axis of rotation generally perpendicular to a plane defined by a surface at said specimen when said specimen is held by said specimen stage.

76. (Cancelled)

77. (Cancelled)

78. (Cancelled)

79. (Cancelled)

80. (Cancelled)

81. (Cancelled)

82. (Cancelled)

83. (Cancelled)

84. (Cancelled)

85. (Cancelled)

86. (Cancelled)

87. (Cancelled)

88. (Cancelled)

89. (Cancelled)

90. (Cancelled)

91. (Cancelled)

92. (Cancelled)

93. (Cancelled)

94. (Cancelled)

95. (Cancelled)

96. (Cancelled)

97. (Cancelled)

98. (Cancelled)

99. (Cancelled)

100. (Cancelled)

101. (Cancelled)

102. (Cancelled)

103. (Cancelled)

104. (Cancelled)

105. (Cancelled)

106. (Cancelled)

107. (Cancelled)

108. (Cancelled)

109. (Cancelled)

110. (Cancelled)

111. (Cancelled)

112. (Cancelled)

113. (Cancelled)

114. (Cancelled)

115. (Cancelled)

116. (Cancelled)

117. (Cancelled)

118. (Previously Presented) An apparatus according to claim 1, further comprising a load lock chamber connected to said process chamber.

119. (Cancelled)

120. (Previously Presented) An apparatus according to claim 68, said etching comprising reactive ion beam etching, said apparatus further comprising a source of reactive process gas connected to said ion source.

121. (Previously Presented) An apparatus according to claim 58, said plasma etching utilizing a plasma generated by capacitive discharge, said plasma etching assembly further comprising an electrode and an alternating voltage source connected to said electrode.

122. (Cancelled)

123. (Cancelled)

124. (Previously Presented) An apparatus according to claim 59, wherein one or more of a size of said gap and a power of said alternating voltage souree are automatically controlled based on parameters set by a user.

125. (Previously Presented) An apparatus according to claim 124, said plasma etching assembly further comprising two or more gas inlets, said process gas comprising a mixture of two or more process gasses selected by a user.

126. (Original) An apparatus according to claim 125, wherein said process gasses further comprise at least one of O_2, CF_4 and CHF_3.

127. (Previously Presented) An apparatus according to claim 1, said means for plasma etching further comprising two or more gas inlets, said plasma etching of said specimen utilizing a plasma generated from a mixture of two or more process gasses selected by a user.

128. (Previously Presented) An apparatus according to claim 1, said means for plasma etching being usable to plasma clean said specimen by generating a plasma from a process gas including oxygen.

129. (Previously Presented) An apparatus according to claim 1, wherein coating comprises ion beam sputter coating, said means for coating comprising a target formed of said conductive material, said ion source directing said ion beam at said target.

130. (Original) An apparatus according to claim 129, said means for coating further comprising a lever supported by said vacuum chamber, said lever holding said target, said lever being selectively moveable into a position in which said ion beam is directed at said target.

131. (Previously Presented) An apparatus according to claim 1, said means for coating comprising a plurality of targets, each of said targets being formed of a conductive material, said ion source directing said ion beam at a selected one of said targets.

132. (Original) An apparatus according to claim 131, said means for coating further comprising means for moving said selected one of said targets from a covered position to an exposed position.

133. (Original) An apparatus according to claim 131, said means for coating further comprising a lever supported by said vacuum chamber, said lever holding said plurality of targets, said lever being selectively moveable into a position in which said ion beam is directed at said selected one of said targets.

134. (Original) An apparatus according to claim 133, said plurality of targets being held by a target holder, said target holder being moveable among a plurality of positions, each of said positions exposing one of said targets and covering a remaining one or more of said targets.

135. (Original) An apparatus according to claim 134, said target holder being rotatably supported by said lever, said target holder being rotatable among said plurality of positions.

136. (Original) An apparatus according to claim 135, said target holder further comprising a plurality of pins, said vacuum chamber supporting an arm, said target holder being

selectively rotated by contact between said arm and any one of said pins.

137. (Original) An apparatus according to claim 133, further comprising means for selectively exposing said selected one of said targets and covering a remaining one or more of said targets.

138. (Cancelled)

139. (Previously Presented) An apparatus according to claim 1, further comprising a sample stage being moveable to a plurality of processing positions inside said vacuum chamber under said continuous vacuum conditions for performing said removing, said plasma cleaning, said plasma etching and said coating of said specimen.

140. (Original) An apparatus according to claim 139, said sample stage being automatically moveable among said processing positions based on parameters set by a user.

141. (Original) An apparatus according to claim 140, said parameters including an order of movement among selected ones of said processing positions.

142. (Original) An apparatus according to claim 139, said sample stage being moveable in a first direction along a vertical axis of said vacuum chamber, said apparatus further comprising means for detecting a first position of a surface of said specimen along said vertical axis, wherein said sample stage is moved automatically to said plurality of processing positions

based on said first position.

143. (Original) An apparatus according to claim 142, wherein said first position is measured relative to a second position along said vertical axis.

144. (Previously Presented) An apparatus according to claim 139, said sample stage being moveable in a first direction along a vertical axis of said vacuum chamber, said apparatus further comprising a beam generating device and a beam sensor supported by said vacuum chamber, said beam generating device and said beam sensor being used to detect a first position of a surface of said specimen along said vertical axis, wherein said sample stage is moved automatically to said plurality of processing positions based on said first position.

145. (Original) An apparatus according to claim 144, wherein said first position is measured relative to a second portion along said vertical axis.

146. (Original) An apparatus according to claim 144, said beam generating device comprising a laser.

147. (Previously Presented) An apparatus according to claim 139, said sample stage being moveable in a first direction along a vertical axis of said vacuum chamber, at least a first portion of said sample stage that supports said specimen being rotatable about said vertical axis, and at least a second portion of said sample stage connected to said first portion being moveable

in a first angular direction with respect to said vertical axis.

148. (Original) An apparatus according to claim 147, at least a third portion of said sample stage connected to said second portion being moveable in a second angular direction with respect to said vertical axis.

149. (Previously Presented) An apparatus according to claim 139, said sample stage having at least three degrees of selective independent movement.

150. (Original) An apparatus according to claim 149, sample stage having at least four degrees of selective independent movement.

151. (Previously Presented) An apparatus according to claim 1, said process chamber having a first aperture adjacent said plasma generator, a first moveable shutter for selectively covering said first aperture, a second aperture adjacent said means for plasma etching, and a second moveable shutter for selectively covering said second aperture.

152. (Withdrawn) A method for preparing a specimen for microscopy, comprising:

determining a first position of a surface of said specimen along an axis of a processing chamber;

automatically moving said specimen to one or more processing locations within said processing chamber based on said first position.

153. (Withdrawn) A method according to claim 152, said determining step further comprising determining said first position relative to a second position along said axis.

154. (Withdrawn) A method according to claim 152, said determining step further comprising:

generating a beam;

directing said beam at a sensor;

moving said specimen along said axis;

establishing said first position when a predetermined level is measured by said sensor.

155. (Withdrawn) A method according to claim 154, said beam comprising a laser beam.

156. (Withdrawn) A method according to claim 154, said predetermined level comprising approximately 50% of a level measured when said sensor is completely unobscured.

157. (Withdrawn) A method according to claim 156, said determining step further comprising:

(a) moving said specimen along said axis to an obscuring position in which said sensor is completely obscured and setting a blocked position variable equal to said obscuring position;

(b) moving said specimen along said axis to an unobscuring position in which

said sensor is completely unobscured, obtaining an unobscured sensor level reading, and setting a clear position variable equal to said unobscuring position;

(c) moving said specimen to a midpoint position that is approximately halfway between a position equal to said blocked position variable and a position equal to said clear position variable;

(d) obtaining a current sensor level reading at said midpoint position;

(e) determining whether said current sensor level reading is equal to approximately 50% of said unobscured sensor level reading;

(f) setting said first position equal to said midpoint position if said current sensor level reading is equal to approximately 50% of said unobscured sensor level reading;

(g) setting said blocked position variable equal to said midpoint position if said current sensor level reading is less than approximately 50% of said unobscured sensor level reading and repeating steps (c) through (h) until said first position is set in step (f); and

(h) setting said clear position variable equal to said midpoint position if said current sensor level reading is greater than approximately 50% of said unobscured sensor level reading and repeating steps (c) through (h) until said first position is set in step (f).

158. (Previously Presented) An apparatus for preparing a specimen for microscopy, comprising:

a processing chamber;

a sample stage, said sample stage being moveable to one or more processing positions inside said processing chamber, said processing position being defined by three dimensional coordinates; and

means for detecting a first position of a surface of said specimen within said processing chamber;

wherein said sample stage is moved automatically to said one or more processing positions remote from said first position in any of three dimensions and at an angle relative to a beam impinging thereon.

159. (Original) An apparatus according to claim 158, wherein said first position is measured relative to a second position along said axis.

160. (Original) An apparatus according to claim 158, said processing positions including positions for performing one or more of etching said specimen, plasma cleaning said specimen, plasma etching said specimen and coating said specimen with a conductive material.

161. (Previously Presented) An apparatus for preparing a specimen for microscopy, comprising:

a processing chamber;

a sample stage, said sample stage being moveable to one or more processing positions inside said processing chamber, said processing positions being defined by three dimensional coordinates; and

a beam generating device and a beam sensor supported by said processing chamber, said beam generating device and said beam sensor being used to detect a first position of a surface of said specimen within said processing chamber;

wherein said sample stage is moved automatically to said one or more processing

positions remote from said first position in any of three dimensions and at an angle relative to said beam generating device.

162. (Original) An apparatus according to claim 161, wherein said first position is measured relative to a second position along said axis.

163. (Original) An apparatus according to claim 161, said processing positions including positions for performing one or more of etching said specimen, plasma cleaning said specimen, plasma etching said specimen and coating said specimen with a conductive material.

164. (Original) An apparatus according to claim 161, said beam generating device comprising a laser.

REMARKS

Reconsideration of the application in view of the following remarks is respectfully requested.

I. Status of the Claims

Claims 1, 3-7, 16-21, 24-31, 58-65, 68, 69, 73-75, 118, 120, 121, 124-137, 139-151, and 158-164 are pending in this application. Claims 152-157 were withdrawn during prior prosecution. In the Office Action mailed on November 6, 2009, claims 1, 3-7, 16-21, 24-31, 58-65, 68, 69, 73-75, 118, 120, 121, 124-135, 137-151 and 158-164 were rejected and claim 136 was objected to as being dependent on a rejected base claim.

Claims 1, 3-7, 16-21, 24-31, 58-65, 68, 69, 73-75, 118, 120, 121, 124-137, 139-151 and 158-164 remain under prosecution.

II. Rejections Under 35 U.S.C. §112, First Paragraph

Claims 1, 3-7, 16-21, 24-31, 58-65, 68, 69, 73-75, 118, 120, 121, 124-137, and 139-151 are rejected under 35 U.S.C. §112, first paragraph as failing to comply with the written description requirement. The Examiner states that there is no support for "selective spatial isolation of said means for plasma etching said specimen and said specimen from said plasma generator, said means for removing material and said means for coating said specimen when said means for plasma etching said specimen is operational." Specifically, the Examiner inquires what element isolates the means for etching from each of the devices. See Office Action page 2.

Applicant respectfully requests reconsideration and withdrawal of the rejection because the Specification discloses several examples of the isolation of the etching means from each of

the other devices. Figure 1 illustrates one embodiment of the invention, showing a device in which specimens may be plasma cleaned, etched or coated alone or in combination under a continuous vacuum state. The specification describes Figure 1 as follows:

> Plasma cleaning, etching and coating apparatus 10 also includes etching and coating chamber 20 made of, for example, stainless steel or aluminum, in which a specimen may be etched, coated, or both. Plasma chamber 15 and etching and coating chamber 20 are connected by vacuum valve 25, which may be manually or automatically actuated. Preferably, vacuum valve 25 is provided with interlocking capability to prevent inadvertent opening of vacuum valvc 25 if plasma chamber 15 and etching and coating chamber 20 are at unequal pressures, such as where one is at atmospheric pressure while the other is under vacuum conditions.

See Specification, page 17, lines 16-22. Thus, Figure 1 clearly illustrates an apparatus for preparing a specimen for microscopy in which an etching chamber is isolated from other devices. The device is provided with a vacuum valve to prevent the mixture of the contents of the plasma chamber 15 and etching and coating chamber 20.

Figure 1 also shows a transfer rod 30 which accommodates one or more sub-mounted specimens 3. Transfer rod 30 moves back and forth between *two separate* chambers-plasma chamber 15 and etching and coating chamber 30-through vacuum valve 25. See Specification page 18, line 21 to page 19, line 1. Transfer rod 30 is described as functioning as follows:

> Etching and coating chamber 20 is at or near its base pressure of, for example, 10^{-7} torr. Vacuum valve 25 is opened and transfer rod 30 is pushed into etching and coating chamber 20 until the gripper 32 is positioned in etching and coating chamber 20 and the specimen stub or stubs 7 engage specimen stage 35. Once the specimen stub 7 engages specimen stage 35, the gripper 32 on the end of transfer rod 30 releases the stub 7 and *is retracted with transfer rod 30 through vacuum valve 25 and vacuum valve 25 is closed.*

Emphasis added. See Specification page 29, lines 11-17.

The specification also describes moveable shutters or baffles positioned in front of viewing window 200 and magnetron sputtering head 105 to "further protect from

deposition of foreign material when not in use." These features are further described as follows:

> For example, the shutter over the magnetron sputtering head 105 prevents deposition of etching products from the ion beam etching onto the magnetron target surface; these products could otherwise be deposited onto the specimen during subsequent magnetron sputter coating. Similarly, the shutter over the viewing window 200 prevents deposition of etching and/or coating products on the viewing window; these products would otherwise interfere with the optical clarity of the window 200.

See Specification page 28, lines 11-18.

In addition, Figure 6 illustrates an apparatus including two vacuum vessels 610 and 620. The port for specimen introduction and removal, the plasma generator and RIE electrode are located in vessel 610, while the ion gun and sputter target are located in vessel 620. The two vessels are joined by a shared valve 630, which serves to *isolate* and/or connect the two vessels. See Specification page 34, lines 5-15. The specification also describes an additional embodiment where the valve 630 is replaced by a moveable baffle that, when closed, blocks the line-of-sight travel between vessels 610 and 620.

Applicant respectfully asserts that specification provides sufficient description of the portion of the claimed apparatus responsible for isolating the means for etching from the other devices. The claims therefore satisfy the written description requirement of 35 U.S.C. § 112, first paragraph. Applicant respectfully requests that the Examiner reconsider and withdraw the rejection in view of at least the foregoing comments.

Claims 1, 3-7, 16-21, 24-31, 58-65, 68, 69, 73-75, 118, 120, 121, 124-137 and 139-151 are rejected under 35 U.S.C. §112, first paragraph as failing to comply with the written description requirement. The Examiner states that the specification does not disclose plasma

cleaning and coating of the specimen in the same chamber. The Examiner further states that Fig. 1 illustrates that these two processes are performed in two chambers. See Office Action page 3.

Applicant respectfully requests reconsideration and withdrawal of the rejection because the Specification discloses several examples of the plasma cleaning and specimen coating processes occurring in the same chamber. The Examiner's attention is directed to Figure 5, which illustrates this single vacuum chamber. Figure 5 is described in the specification at page 20, lines 15 - 21 and page 21, lines 17 - 20:

> In another embodiment of the present invention, shown schematically in Figure 5, the apparatus includes one vacuum vessel 510 having a vacuum pump 511 generally similar to vacuum pump 410 of Figure 4, a port for inserting and extracting specimens 1, a specimen stage 35 for holding an manipulating specimens 1, ***a plasma generator 520 for plasma cleaning***, an ion gun 130 for ion beam etching, a moveable electrode 530 for performing RIE, and ***a sputter target 540 working in combination with ion gun 130 for depositing conductive coatings by an ion beam sputtering process***.
>
> ***
>
> The apparatus shown in Figure 5 thus enables ion milling, plasma etching, plasma cleaning and/or coating steps to be performed in any order, any number of times, and according to various operating parameters while specimen 1 is under continuous vacuum conditions (emphasis added).

In addition, the Specification at page 24, line 33 to page 27, line 17 and Figures 8, 10 and 11 describes a single chamber device. With reference to Figures 8 and 11, the device contains a plasma generator housed within shield 897 for plasma cleaning the specimen within the vacuum chamber. A sputtering process to coat the specimen is performed in the same chamber using an ion source 910 in combination with a sputter target ("Apparatus 800 is also adapted to deposit conductive coatings on specimen 835."). *See* Specification page 26, lines 27-28 and Figure 10. A moveable shutter 905 is provided in the vacuum chamber 805 that may move to cover the aperture 900 when plasma cleaning is not in process. This is done to protect the components of the plasma generator during other specimen preparation procedures. The specification therefore

describes a single chamber device which utilizes moveable shutters or baffles to separate or protect the different cleaning and coating devices. Although these mechanisms are fully separated from each other, they are still located within the same vacuum chamber.

Applicant respectfully asserts that specification provides sufficient description of a single chamber system. The claims therefore satisfy the written description requirement of 35 U.S.C. § 112, first paragraph. Withdrawal of the rejection is respectfully requested.

III. Rejections Under 35 U.S.C. § 103

The Examiner rejected claims 1, 3-7, 21, 24, 25, 58-64, 68, 69, 73, 74, 121, 124, 129, 139, 140, 141, 142, 143, 149 and 151 under 35 U.S.C. § 103(a) as being obvious over Siebert, United States Patent No. 4,858,556 in view of Moslehi, United States Patent No. 6,051,113, Mahler, United States Patent No. 4,595,483 and Miyoshi, United States Patent No. 6,325,857. See Office Action pages 4-10.

The Examiner rejected claims 16 and 65 under 35 U.S.C. § 103(a) as being obvious over Siebert in view of Moslehi, Mahler, Miyoshi and further in view of Ameen, et al., United States Patent No. 6,143,128. See Office Action page 9.

The Examiner rejected claims 17-20 under 35 U.S.C. § 103(a) as being obvious over Siebert in view of Moslehi, Mahler, Miyoshi and Ameen, and further in view of Chang, et al., United States Patent No. 6,434,814. See Office Action page 10.

The Examiner rejected claims 26-29, 75, 147, 148 and 150 under 35 U.S.C. § 103(a) as being obvious over Siebert in view of Moslehi, Mahler, Miyoshi and further in view of Mitro, et al., United States Patent No. 5,922,179. See Office Action page 11.

The Examiner rejected claim 30 under 35 U.S.C. § 103(a) as being obvious over Siebert in view of Moslehi, Mahler and Miyoshi and further in view of Kobayashi, et al., United States Patent No. 5,340,460. See Office Action page 12.

The Examiner rejected claim 31 under 35 U.S.C. § 103(a) as being obvious over Siebert in view of Moslehi, Mahler and Miyoshi and further in view of Holland, United States Patent No. 5,311,725. See Office Action pages 12-13.

The Examiner rejected claim 118 under 35 U.S.C. § 103(a) as being obvious over Siebert in view of Moslehi, Mahler and Nomura and further in view of Nomura, et al., United States Patent No. 6,641,703. See Office Action page 13.

The Examiner rejected claims 120 and 125-128 under 35 U.S.C. § 103(a) as being obvious over Siebert in view of Moslehi, Mahler and Miyoshi and further in view of Chang, et al., United States Patent No. 6,434,814. See Office Action pages 13-14.

The Examiner rejected claims 130-135 and 137 under 35 U.S.C. § 103(a) as being obvious over Siebert in view of Moslehi, Mahler and Miyoshi and further in view of Hurwitt, United States Patent No. 3,756,939. See Office Action pages 14-15.

The Examiner rejected claims 144-146 under 35 U.S.C. § 103(a) as being obvious over Siebert in view of Moslehi, Mahler and Miyoshi and further in view of Baldwin, et al., United States Patent No. 6,419,802. See Office Action pages 15-16.

The Examiner rejected claims 158-160 under 35 U.S.C. § 103(a) as being obvious over Moslehi in view of Mitro and Baldwin. See Office Action pages 16-17

The Examiner rejected claims 161-164 under 35 U.S.C. § 103(a) as being obvious over Moslehi in view of Mitro and Baldwin. See Office Action pages 18-19.

The claimed invention requires that the plasma etching functionality be ***isolated*** from the other component functionalities of the device ***when said means for plasma etching said specimen is operational***. As explained previously, this spatial limitation requires that the highly corrosive etching hardware be separated physically from the other functional devices. Applicant continues to contend that this is not taught nor suggested in the prior art. The Siebert reference does identify a shutter which rotates to expose the specimen to the appropriate operative hardware, and which is stated to provide additional substrate protection. However, no further disclosure is made and Fig. 7 merely identifies it as a standalone, line of sight shield between the various operative hardware and the specimen. Moreover, the testing or detection devices of the Siebert reference are still contained within the chamber with the specimen. The shutter is not shown to spatially separate the specimen and plasma etching mechanism from the other operative components. The Examiner relies on a single, nonspecific reference to other devices, "the sources 18 may be any of a number of different types of sources. . ." (col. 12, lines 24-25). This is the Examiner's basis for linking ***three*** additional references to arguably find all of the elements of the claimed invention.

KSR International Co. v. Teleflex Inc., 550 U.S. 398, 127 S.Ct. 1727, 167 L.Ed.2d 705 (2007) disposes of the heretofore enunciated standard requiring a teaching, suggestion or motivation to combine references, in order to avoid improper hindsight reconstruction. *Id.* at 1742. The TSM standard has not been completely disavowed, however. A flexible TSM standard has been approved by the United States Court of Appeals for the Federal Circuit, following the KSR ruling.

> [T]he Supreme Court advised that 'common sense' would extend the use of customary knowledge in the obviousness equation: 'A person of ordinary skill is also a person of ordinary creativity, not an automaton.' *Id.* Thus, the Supreme Court set aside any 'rigid' application of the TSM test and ensured use of

> customary knowledge as an ingredient in that equation. The Supreme Court observed that this court had also 'elaborated a broader conception of the TSM test than was applied in [KSR]. *Id.* at 1743. Specifically the Court referred to *DyStar Textilfarben GmbH & Co. v. C.H. Patrick Co.*, wherein this court noted: '[o]ur suggestion test is in actuality quite flexible and not only permits, but requires, consideration of common knowledge and common sense.' 464 F.3d 1356, 1367 (Fed.Cir.2006) (emphasis original). The Court suggested that this formulation would be more consistent with the Supreme Court's restatement of the TSM test. *KSR Int'l Co.,* 127 S.Ct. at 1739. In any event, as the Supreme Court suggests, a flexible approach to the TSM test prevents hindsight and focuses on evidence before the time of invention, see, e.g., *In re Rouffet,* 149 F.3d 1350, 1357 (Fed.Cir.1998), without unduly constraining the breadth of knowledge available to one of ordinary skill in the art during the obviousness analysis.

In re Translogic Technology, Inc., 504 F.3d 1249, 1260 (Fed.Cir. 2007). Pre-TSM courts utilize standards which are entirely consistent with this formulation. *In re Fine,* 837 F.2d 1071, 1073-75 (Fed.Cir. 1988), states:

> To reach a proper conclusion under § 103, the decisionmaker must step backward in time and into the shoes worn by [a person having ordinary skill in the art] when the invention was unknown and just before it was made. In light of all the evidence, the decisionmaker must then determine whether ... the claimed invention as a whole would have been obvious at that time to that person. The answer to that question partakes more of the nature of law than of fact, for it is an ultimate conclusion based on a foundation formed of all the probative facts . . . It can satisfy this burden only by showing some objective teaching in the prior art or that knowledge generally available to one of ordinary skill in the art would lead that individual to combine the relevant teachings of the references . . . It is essential that 'the decisionmaker forget what he or she has been taught at trial about the claimed invention and cast the mind back to the time the invention was made . . . to occupy the mind of one skilled in the art who is presented only with the references, and who is normally guided by the then-accepted wisdom in the art.' One cannot use hindsight reconstruction to pick and choose among isolated disclosures in the prior art to deprecate the claimed invention (citations omitted).

In this case, as in *Ortho-McNeil Pharmaceutical, Inc. v. Mylan Laboratories, Inc.,* 520 F.3d 1358 (Fed.Cir. 2008), the references amply support a finding of nonobviousness. "The challenges of this inventive process would have prevented one of ordinary skill in this art from traversing the multiple obstacles to easily produce the invention in light of the evidence available at the time of invention." *Id.* at 1365. Siebert merely discloses the potential use of other sources.

It contains no further disclosure, nor any separation therebetween. Figure 2 identifies the different sputter and ion beam sources as all interchangeable above a rotating shutter. The shutter itself is merely a movable shade to temporarily block the emissions of the source from the specimen. Miyoshi discloses a chamber which is utilized to prepare a reactive material for exposure to the specimen. The chamber is sealed by a movable shutter. The shutter is closed to allow the reactant materials to enter the chamber in a controlled environment. When the reaction has produced the appropriate products, **the shutter is opened and the specimen is exposed to the material. The shutter is therefore utilized to** encapsulate the reactive materials, not shield the specimen or other fixtures in the chamber. Contrary to the Examiners assertions, the shutter of Miyoshi *would not* function to isolate one means from another so that the different processes do not affect the functionalities of the other components. In the most recent office action, the Examiner has stated, on Page 8, "[r]egarding isolating the etching means form[sic] the other means (claim 1), Miyoshi teach[sic] a shutter which isolates [sic] means from an etching means" (referring to column 9, lines 62-68 and column 10, lines 1-4. This specific reference to Miyoshi teaches that the shutter is utilized to shield the catalyzer holder 2 (the source) from the operation of the cleaning device 5. ***The shutter 4 is utilized to shield the catalyzer (source) from the operation of the cleaner which is utilized to clean the interior of the chamber and specimen stage when the device is not in operational use to perform any etching, cleaning or coating of a specimen.*** Neither Siebert nor Miyoshi teaches or suggests that a shutter may be utilized to shield different reactive components or fixtures during the use of other source components within a closed vacuum chamber during the operation of a source on the specimen. This is not a case where one element has merely been substituted for another. A rote combination of the teachings of Sieber, Moslehi, Mahler and Miyoshi would not result in the claimed invention.

The combination yields more than a predictable result, as required by *United States v. Adams,* 383 U.S. 39, 50-51 (1966), cited with approval by *KSR.* The claimed invention combines the heretofore disparate functionalities of plasma cleaning, etching with plasma and otherwise, and coating are all performed in the same chamber under continuous vacuum. This is especially true of plasma etching, which does not readily combine with other processes. None of these references recognizes the need to isolate the plasma etching function during operational etching of the specimen with particularity, nor do they recognize any need for separation of the functions. To stuff all of the identified features in a box does not yield a useful device. Even placing the Miyoshi reaction chamber into a common vacuum chamber would not yield the claimed device, as the device segregates the plasma etching function ***while operational with respect to the substrate***, and not as a preparatory or ***maintenance*** step.

As stated by the Examiner, some hindsight is necessary in any obviousness evaluation. However, the MPEP clearly states:

> Knowledge of applicant's disclosure must be put aside in reaching this determination, yet kept in mind in order to determine the 'differences,' conduct the search and evaluate the 'subject matter as a whole' of the invention. The tendency to resort to 'hindsight' based upon applicant's disclosure is often difficult to avoid due to the very nature of the examination process. However, impermissible hindsight must be avoided and the legal conclusion must be reached on the basis of the facts gleaned from the prior art.

MPEP §2142. Applicant respectfully reasserts that the Examiner is applying impermissible hindsight in the evaluation of the above-cited prior art references. None of the prior art references, either alone or in combination, teaches or suggests a shutter to shield different reactive components or fixtures during the use of other source components during the operation of a source on the specimen. Withdrawal of the rejection is respectfully requested.

CONCLUSION

Based on the foregoing remarks, Applicant respectfully submits that claims 1, 3-7, 16-21, 24-31, 58-65, 68, 69, 73-75, 118, 120, 121, 124-137, 139-151, and 158-164 are in condition for allowance.

Applicants believe there are no fees necessary to file this Response. If this is incorrect, the Office is hereby authorized to charge any additional fees under 37 C.F.R. § 1.17 to the deposit account number 50-0525.

Respectfully submitted,

By /Barry I. Friedman/

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Dated: February 8, 2010

(412) 918-1100

United States Patent [19]

Siebert

[11] Patent Number: 4,858,556

[45] Date of Patent: Aug. 22, 1989

[54] METHOD AND APPARATUS FOR PHYSICAL VAPOR DEPOSITION OF THIN FILMS

[76] Inventor: Jerome F. Siebert, 5991 S. Vale Rd., Boulder, Colo. 80303

[21] Appl. No.: 907,274

[22] Filed: Sep. 15, 1986

[51] Int. Cl.^{4} C23C 16/00

[52] U.S. Cl. 118/664; 118/690; 118/708; 118/715; 118/725; 118/726; 118/730; 219/72; 219/209; 156/345

[58] Field of Search 118/664, 690, 708, 715, 118/725, 726, 730; 219/72, 209; 156/345

[56] References Cited

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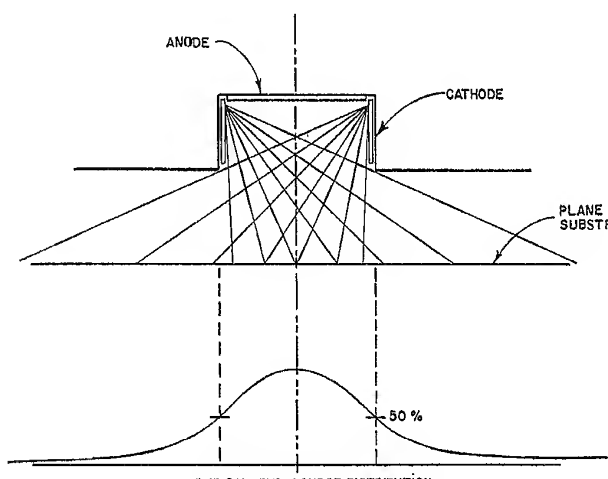
Primary Examiner—Richard Bueker
Attorney, Agent, or Firm—Gerald J. Ferguson, Jr.

[57] ABSTRACT

A physical vapor deposition system is disclosed for routinely achieving unprecedented processing uniformity of thin films on substrates of a size comparable to or larger than the source. The system includes a plurality of substrates; a plurality of deposition, etching, and/or heating sources; a plurality of mobile in-situ process monitors for obtaining the fundamental processing profiles that characterize the processing properties of each source; and mobile fixturing responsive to the fundamental processing profiles for effecting prescribed motion scenarios of the substrate relative to the source; to thus provide the means for achieving extremely uniform as well as an unprecedented range of prescribed non-uniform final thin film processing profiles, irrespective of the size of the substrate relative to the size of the source.

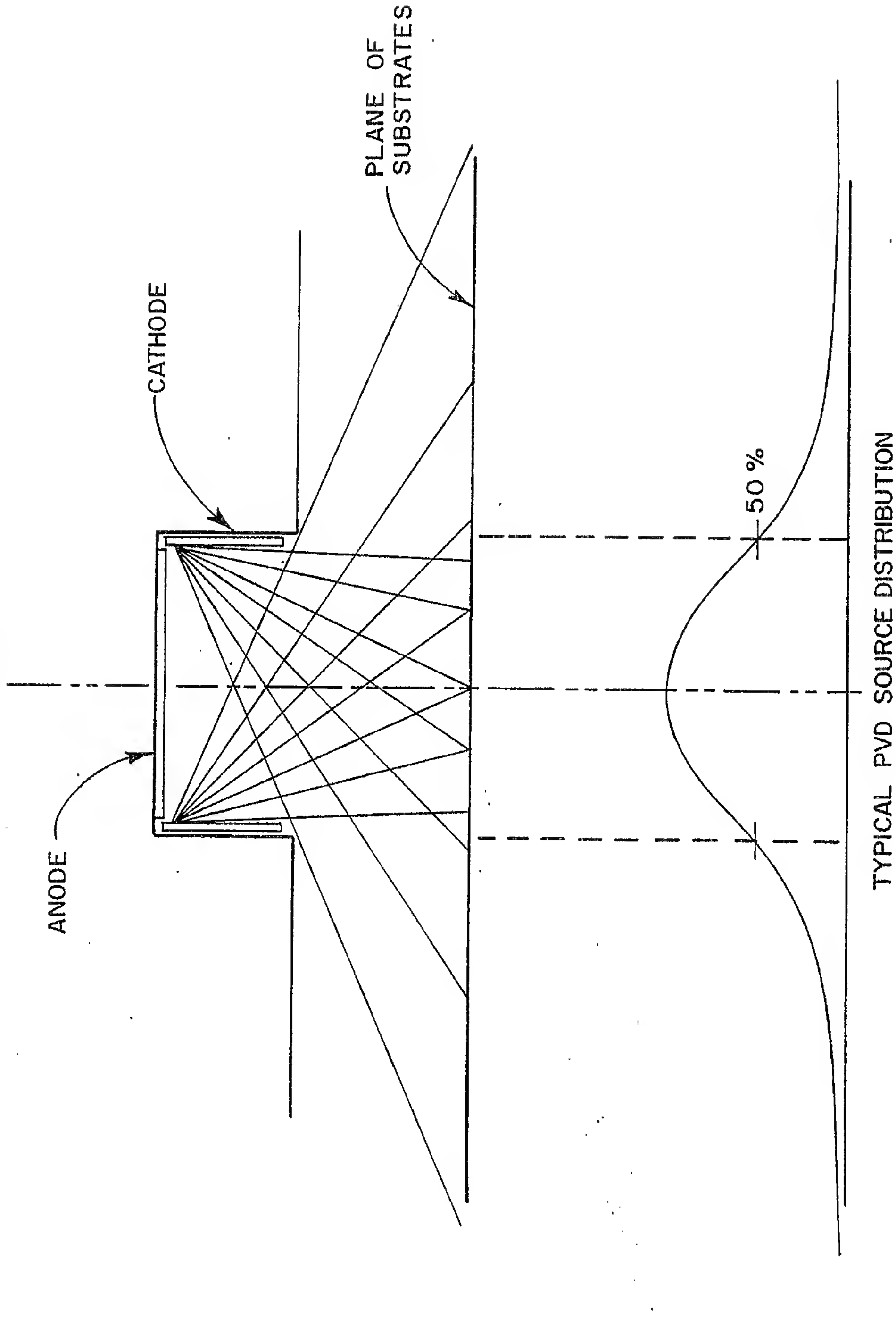
47 Claims, 16 Drawing Sheets



TYPICAL PVD SOURCE DISTRIBUTION

Exhibit C

FIG. 1


CATHODE
PLANE OF SUBSTRATES
ANODE
50 %
TYPICAL PVD SOURCE DISTRIBUTION

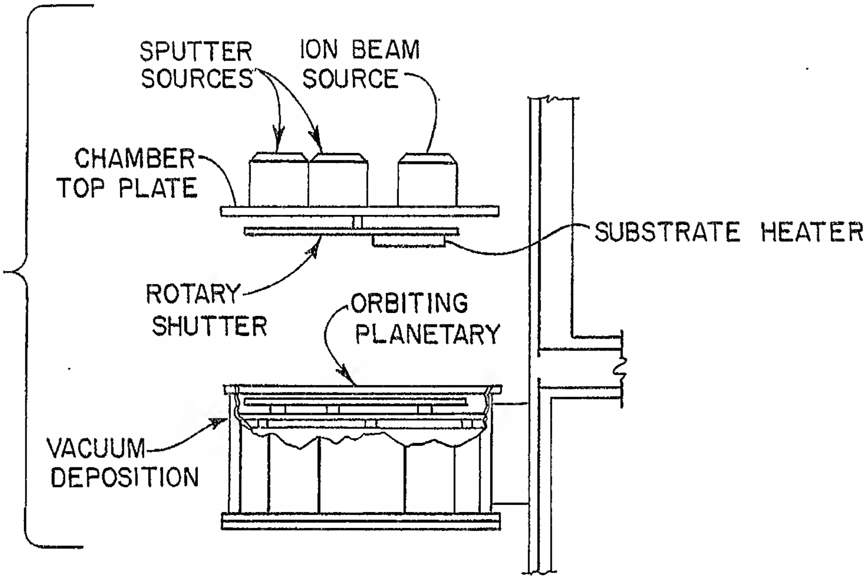

SPUTTER
SOURCES
ION BEAM
SOURCE
CHAMBER
TOP PLATE
SUBSTRATE HEATER
ROTARY
SHUTTER
ORBITING
PLANETARY
VACUUM
DEPOSITION

FIG.2

FIG. 3

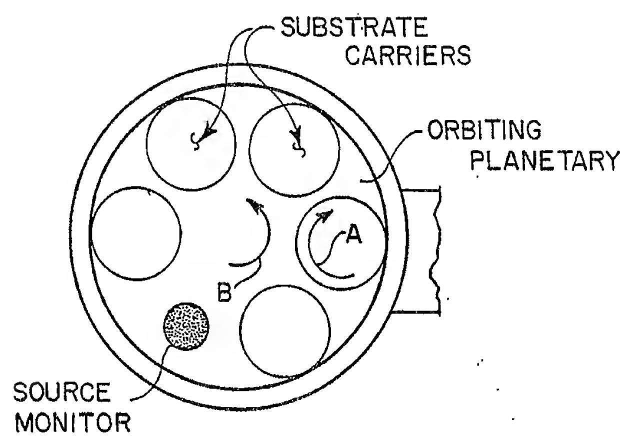

SUBSTRATE
CARRIERS
ORBITING
PLANETARY
A
B
SOURCE
MONITOR

FIG. 4

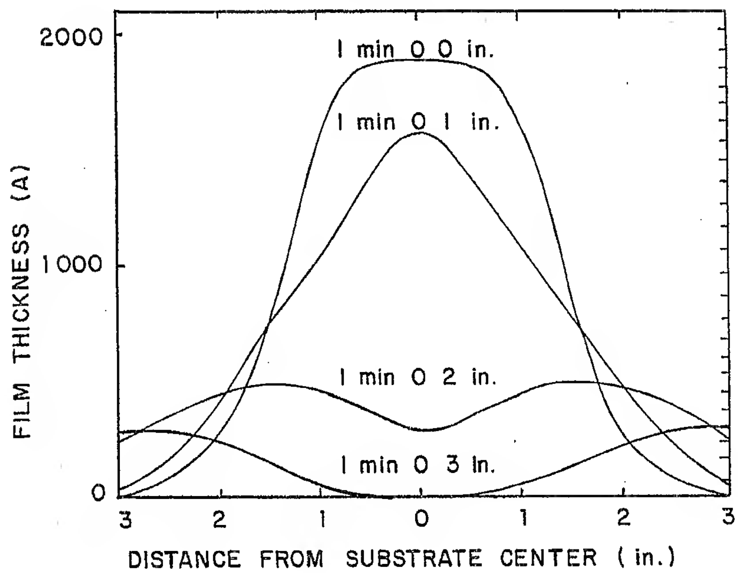
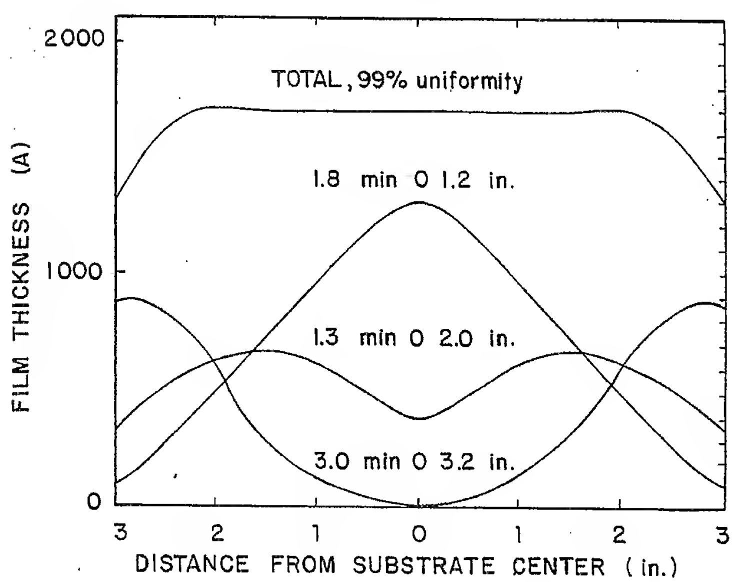

2000
1000
0
FILM THICKNESS (A)
1 min O 0 in.
1 min O 1 in.
1 min O 2 in.
1 min O 3 in.
3
2
1
0
1
2
3
DISTANCE FROM SUBSTRATE CENTER (in.)

FIG. 5


2000
1000
0
FILM THICKNESS (A)
TOTAL, 99% uniformity
1.8 min O 1.2 in.
1.3 min O 2.0 in.
3.0 min O 3.2 in.
3
2
1
0
1
2
3
DISTANCE FROM SUBSTRATE CENTER (in.)

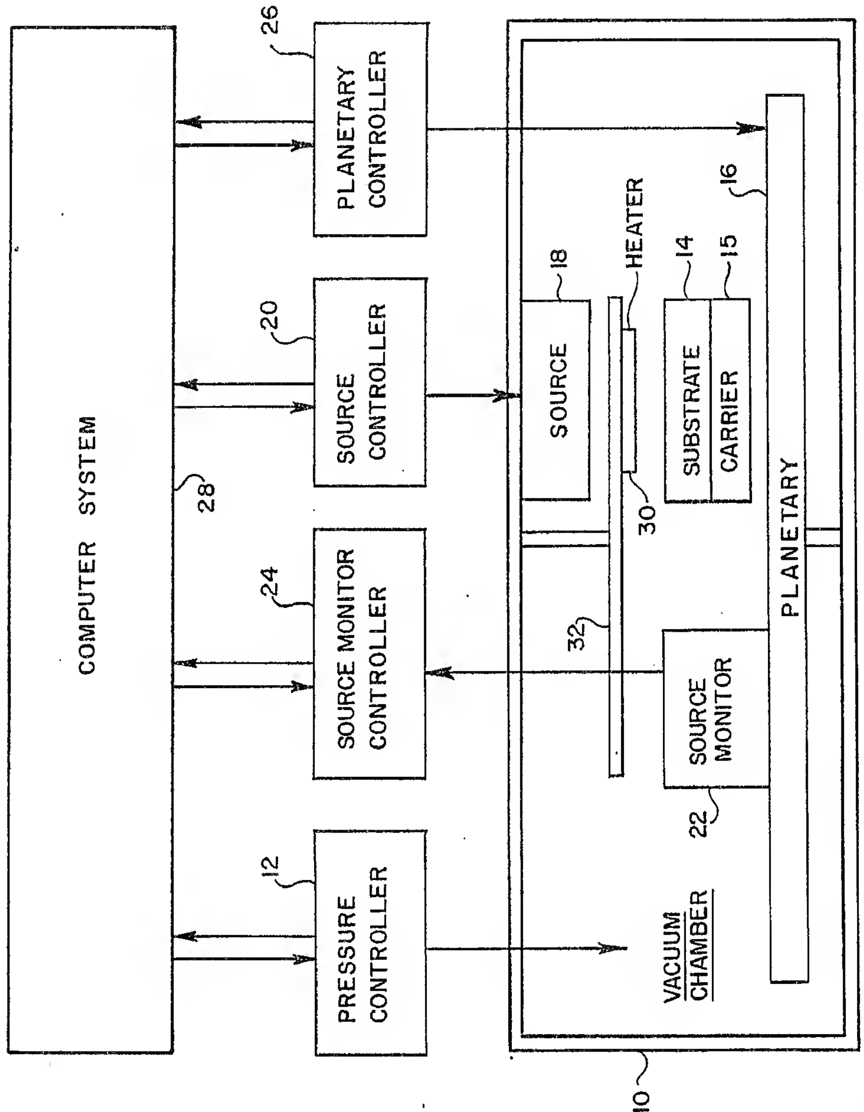
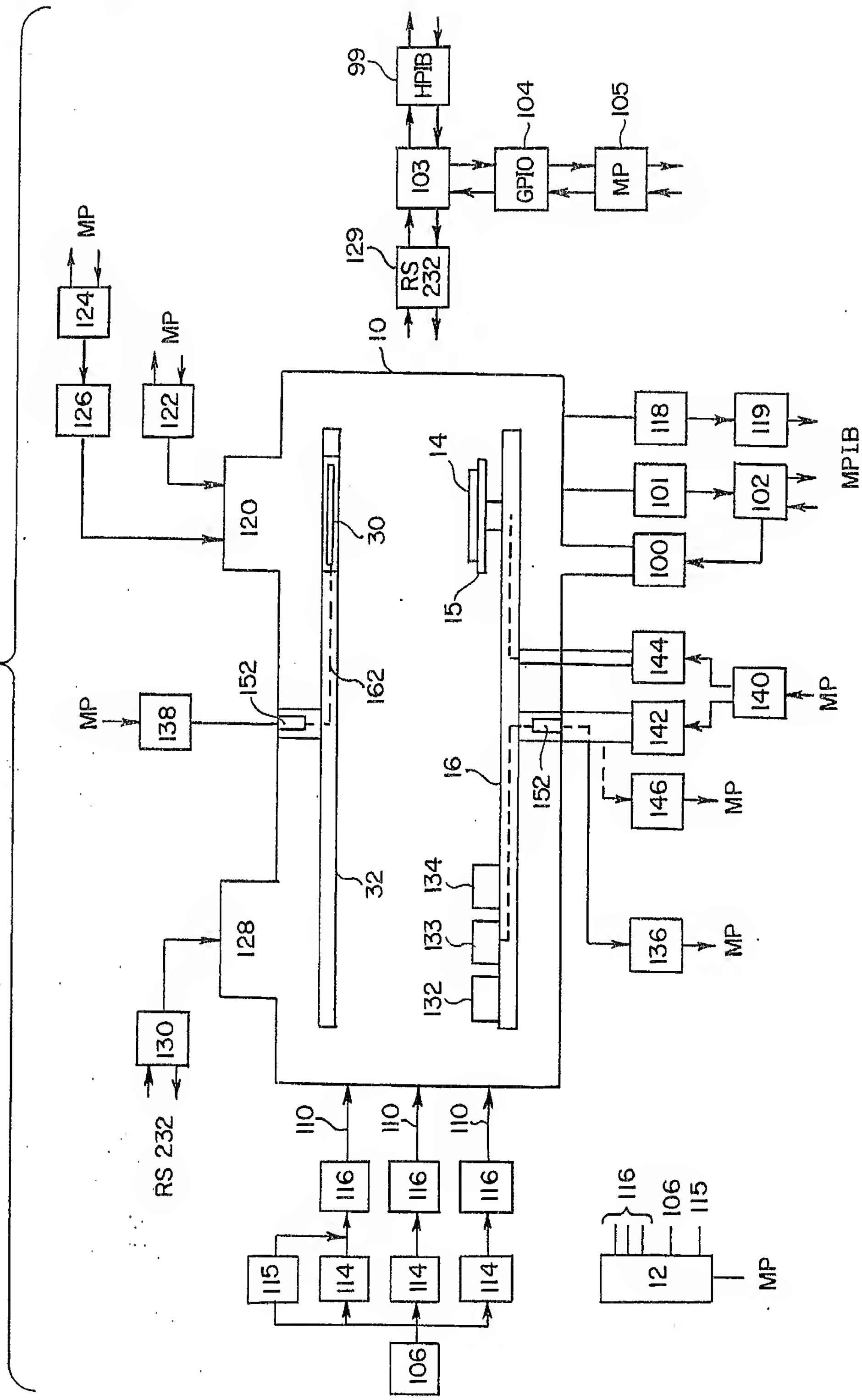


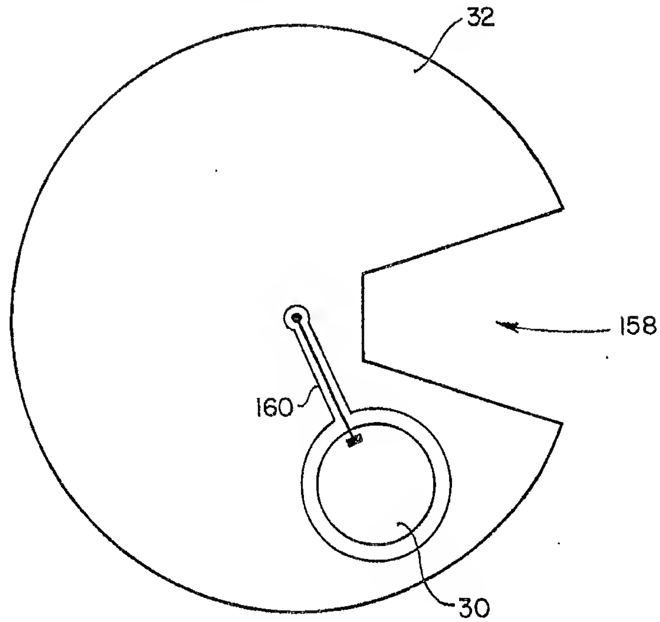
FIG. 6 PHYSICAL VAPOR DEPOSITION SYSTEM FUNCTIONAL HARDWARE BLOCK DIAGRAM



99
HPIB
103
GPIO
104
MP
105
129
RS 232
10
MP
124
126
122
120
30
14
15
118
119
101
102
MPIB
100
152
162
144
140
142
138
16
146
134
133
132
32
128
136
130
RS 232
110
116
115
114
106
12

FIG. 7

FIG. 11



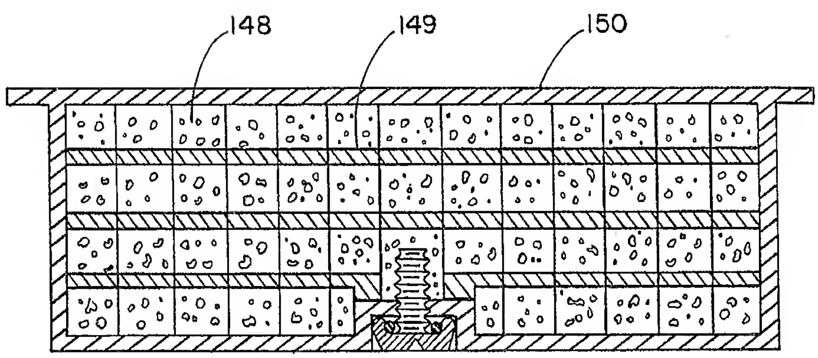


FIG. 8

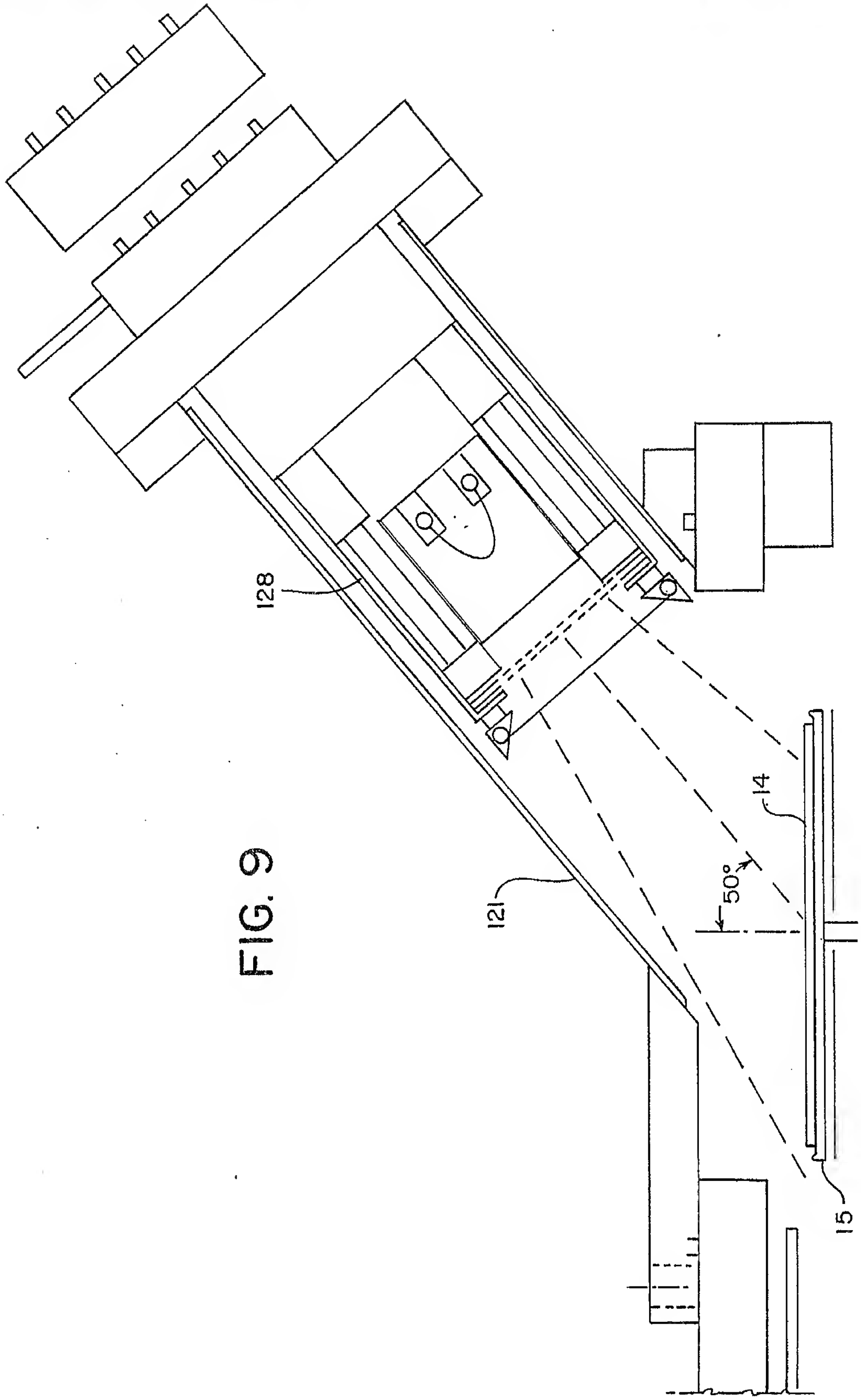


FIG. 9

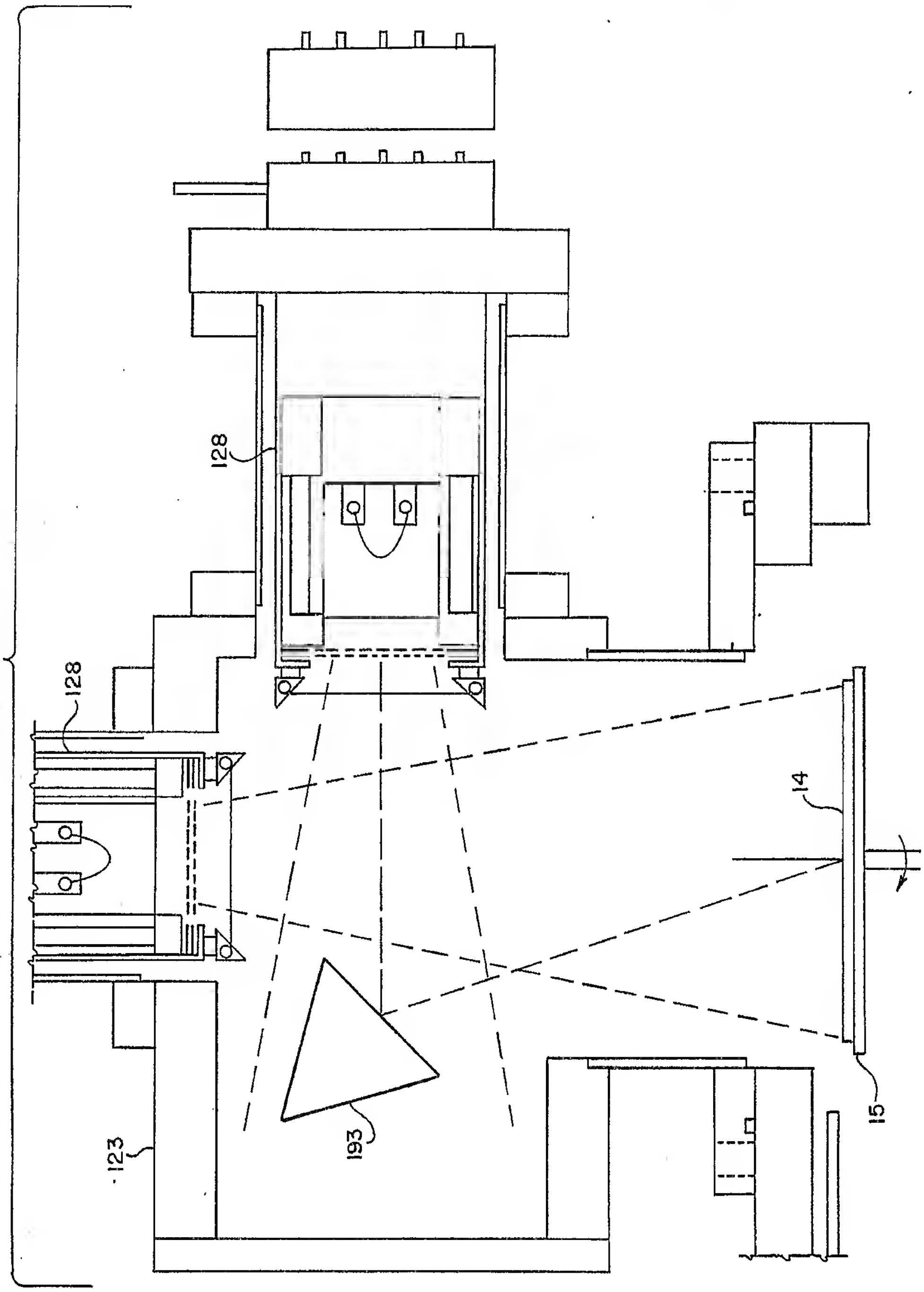


FIG. 10

FIG. 12

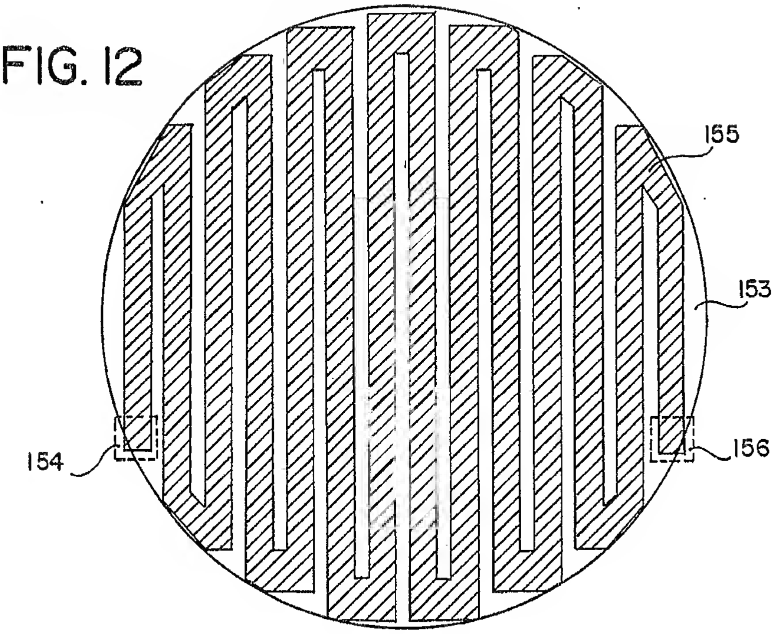
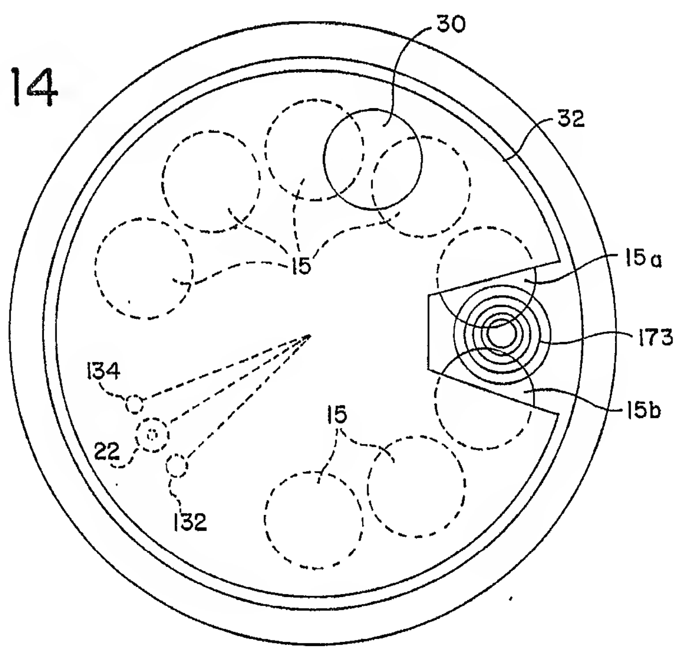


FIG. 14



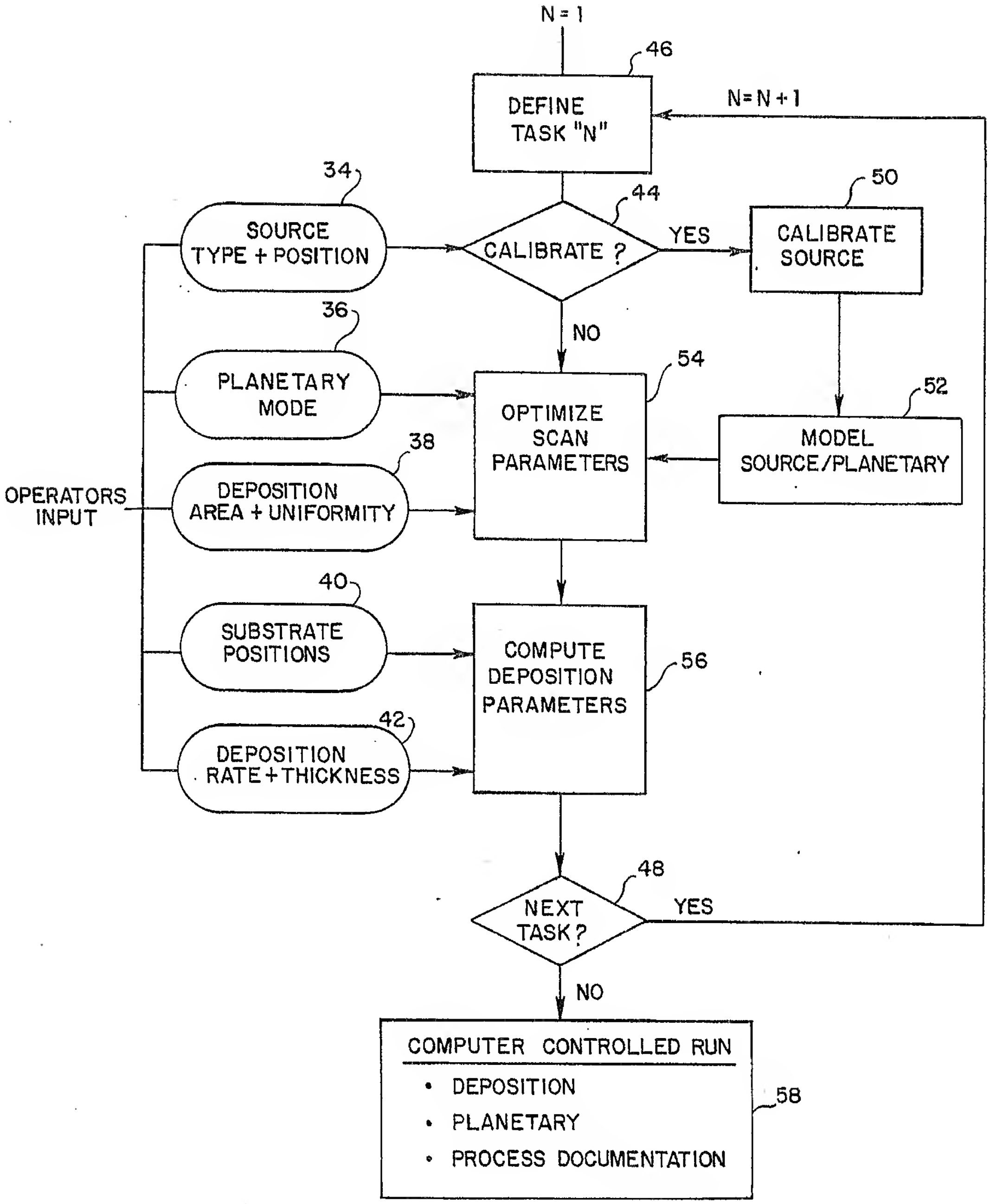
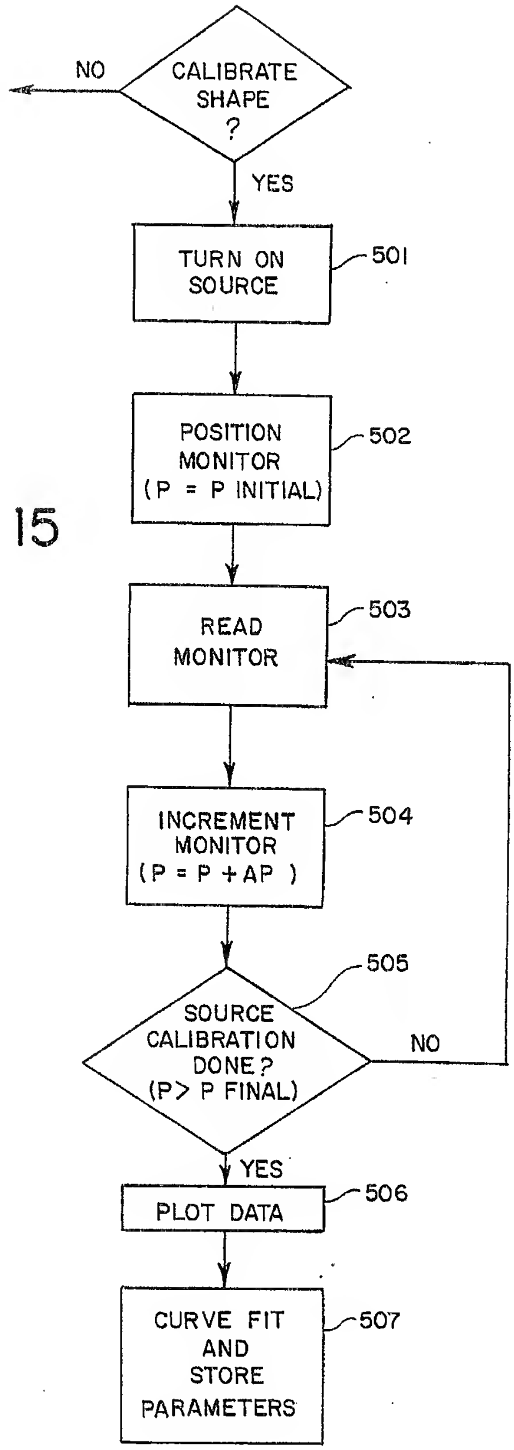


FIG. 13 PHYSICAL VAPOR DEPOSITION SYSTEM FUNCTIONAL FLOW DIAGRAM

FIG. 15


CALIBRATE SHAPE ?
NO
YES
TURN ON SOURCE
501
POSITION MONITOR (P = P INITIAL)
502
READ MONITOR
503
INCREMENT MONITOR (P = P + AP)
504
SOURCE CALIBRATION DONE ? (P> P FINAL)
505
NO
YES
PLOT DATA
506
CURVE FIT AND STORE PARAMETERS
507

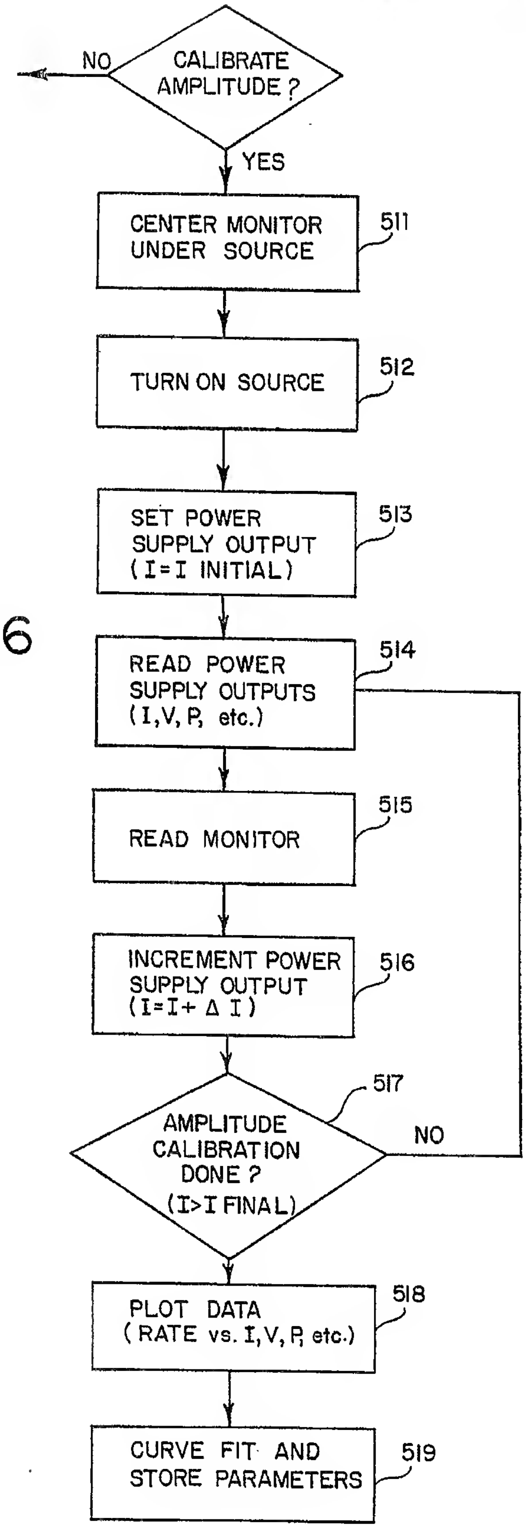

CALIBRATE AMPLITUDE ?
NO
YES
CENTER MONITOR UNDER SOURCE
511
TURN ON SOURCE
512
SET POWER SUPPLY OUTPUT (I=I INITIAL)
513
READ POWER SUPPLY OUTPUTS (I,V,P, etc.)
514
READ MONITOR
515
INCREMENT POWER SUPPLY OUTPUT (I=I+ Δ I)
516
517
AMPLITUDE CALIBRATION DONE ? (I>I FINAL)
NO
PLOT DATA (RATE vs. I,V,P, etc.)
518
CURVE FIT AND STORE PARAMETERS
519

FIG. 16

FIG. 17

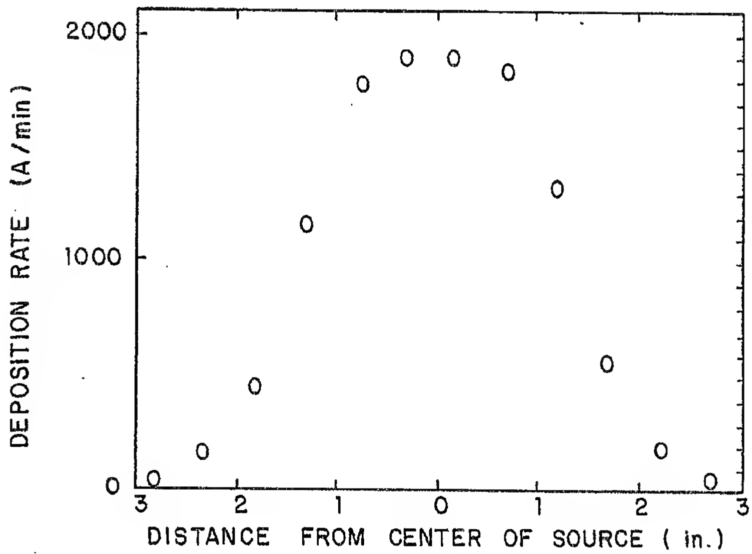
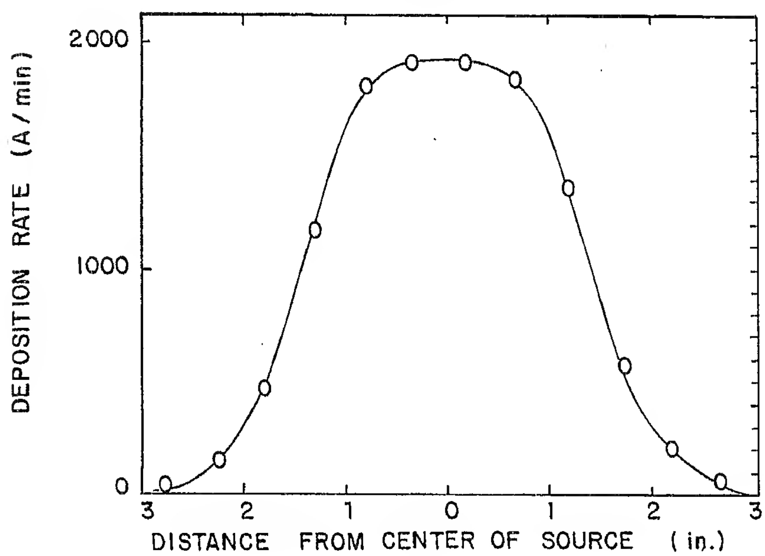

DEPOSITION RATE (A/min)
2000
1000
0
3
2
1
0
1
2
3
DISTANCE FROM CENTER OF SOURCE (in.)

FIG. 18


DEPOSITION RATE (A/min)
2000
1000
0
3
2
1
0
1
2
3
DISTANCE FROM CENTER OF SOURCE (in.)

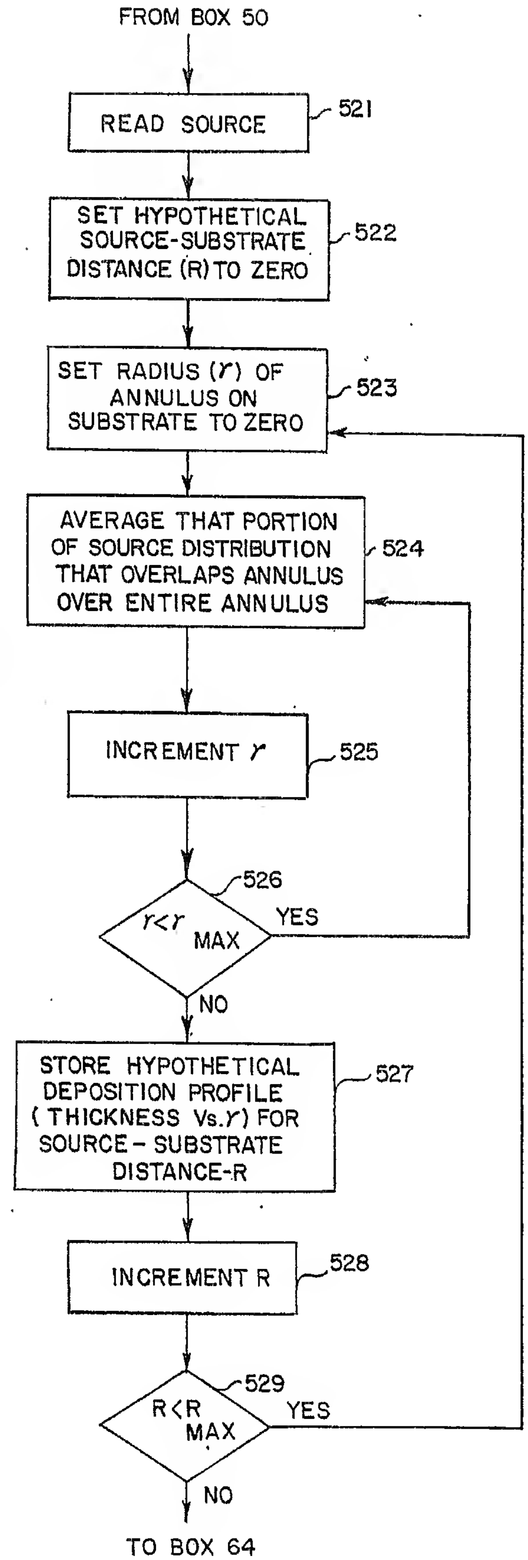

FROM BOX 50
READ SOURCE
521
SET HYPOTHETICAL SOURCE-SUBSTRATE DISTANCE (R) TO ZERO
522
SET RADIUS (r) OF ANNULUS ON SUBSTRATE TO ZERO
523
AVERAGE THAT PORTION OF SOURCE DISTRIBUTION THAT OVERLAPS ANNULUS OVER ENTIRE ANNULUS
524
INCREMENT r
525
526
r<r MAX
YES
NO
STORE HYPOTHETICAL DEPOSITION PROFILE (THICKNESS Vs. r) FOR SOURCE - SUBSTRATE DISTANCE-R
527
INCREMENT R
528
529
R<R MAX
YES
NO
TO BOX 64

FIG. 19

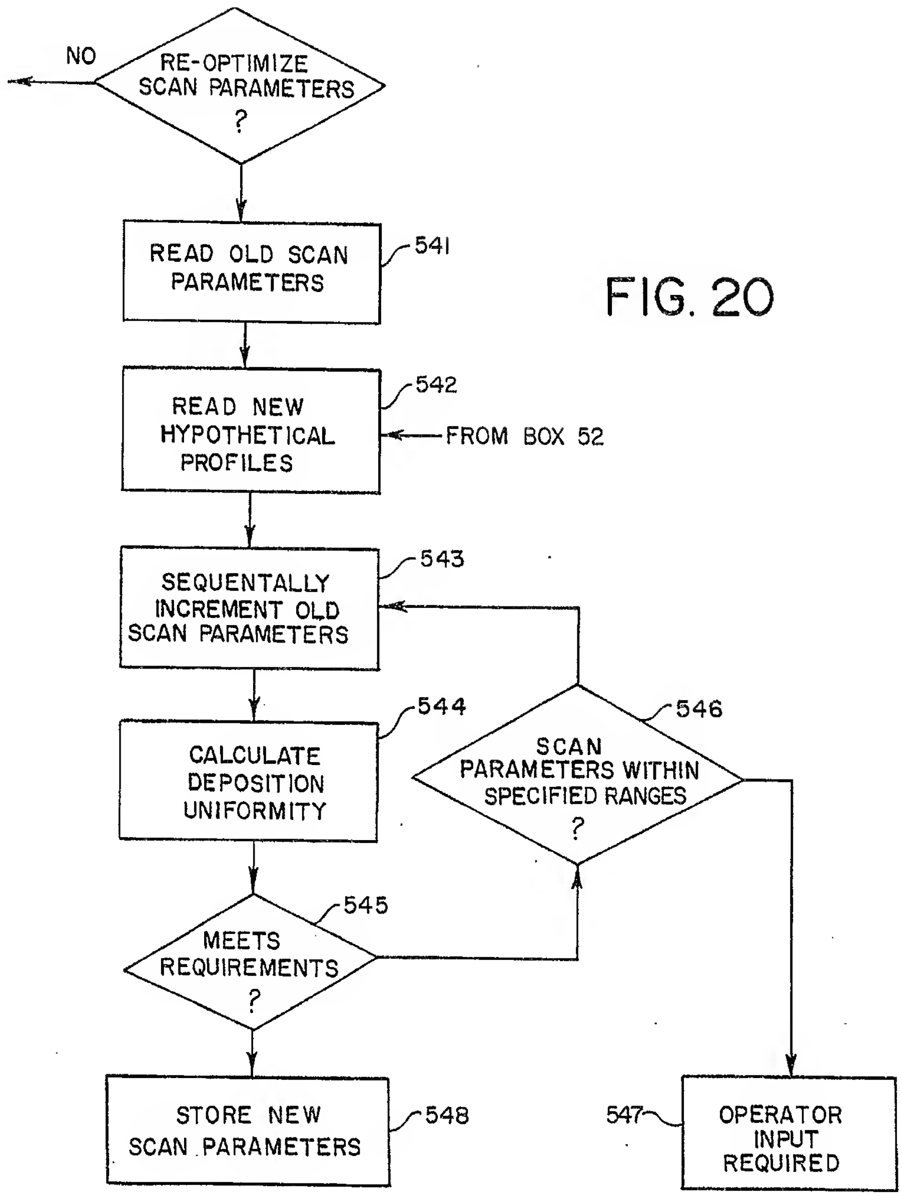
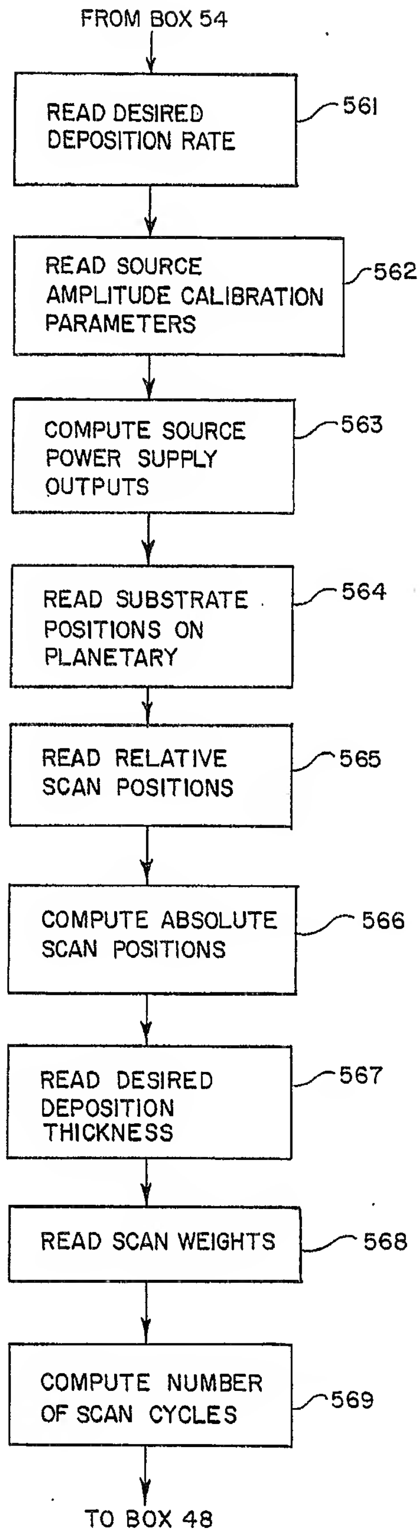

NO
RE-OPTIMIZE SCAN PARAMETERS ?
READ OLD SCAN PARAMETERS
541
READ NEW HYPOTHETICAL PROFILES
542
FROM BOX 52
SEQUENTIALLY INCREMENT OLD SCAN PARAMETERS
543
CALCULATE DEPOSITION UNIFORMITY
544
SCAN PARAMETERS WITHIN SPECIFIED RANGES ?
546
MEETS REQUIREMENTS ?
545
STORE NEW SCAN PARAMETERS
548
547
OPERATOR INPUT REQUIRED

FIG. 20

FIG. 21


FROM BOX 54
READ DESIRED DEPOSITION RATE
561
READ SOURCE AMPLITUDE CALIBRATION PARAMETERS
562
COMPUTE SOURCE POWER SUPPLY OUTPUTS
563
READ SUBSTRATE POSITIONS ON PLANETARY
564
READ RELATIVE SCAN POSITIONS
565
COMPUTE ABSOLUTE SCAN POSITIONS
566
READ DESIRED DEPOSITION THICKNESS
567
READ SCAN WEIGHTS
568
COMPUTE NUMBER OF SCAN CYCLES
569
TO BOX 48

METHOD AND APPARATUS FOR PHYSICAL VAPOR DEPOSITION OF THIN FILMS

BACKGROUND OF THE INVENTION

The present invention relates to a method and apparatus for the deposition, etch, and/or thermal processing of thin films in physical vapor deposition (PUD) systems.

Processing of increasingly pure and uniform thin films of a wide variety of materials onto an equally wide variety of types and sizes of substrate materials is a key processing requirement in the manufacture of many high technology products including integrated circuits, magnetic and optical memory media, active and passive solar energy devices, and optical coatings. There are several types of processes that may be carried out in PUD systems including thermal evaporation, ion-beam etching and magnetron sputtering, and molecular-beam epitaxy to mention just a few.

A common problem with each of these processes is how to uniformly process high-purity homogeneous films over any given substrate area, while maintaining acceptable commercial throughputs and source efficiencies. This problem is illustrated in FIG. 1 for the particular case of a ring magnetron sputtering source, although the following discussion is equally applicable to all sources commonly utililized in PUD systems. As shown in FIG. 1, the distribution of sputtered material at the substrate plane is highly nonuniform. The amplitude (deposition rate) and shape (profile) of this distribution depend not only on the type, design, and operating conditions (e.g., deposition chamber pressure) of the source, but also on the particular source material (target), the state of erosion (usage) of the source material, and the source-to-substrate spacing. (Note that the properties of the substrate may also influence the source distribution. For most sources on PUD systems this influence is typically small and/or predictable. This is to be contrasted with other thin film processing techniques such as chemical vapor deposition (CUD), where the effect of the substrate on the deposition may be a dominate factor.)

The PUD equipment industry had developed the following techniques for achieving more uniform processing of thin films:

a. Use processing sources much larger than the substrates.

b. Use tuning electric and magnetic fields, shadow masks, etc. to shape the source distribution.

c. Use substrate motion to average the source distribution.

d. Various combinations of the above.

The problem with the first brute-force technique is its obvious inefficiency. Not only is it wasteful and expensive, especially for precious metal depositions, the use of very large sources sets off a chain reaction of increased size and cost and reduced versatility in the PUD equipment design and performance. In particular, research and development (R&D) in a production PVD system (or vice-versa) is a difficult, expensive, and unrewarding undertaking. Using separate systems for R&D and production is one approach, but this requires that processing techniques developed on an R&D system be efficiently and accurately transferred to a production system. This time required in getting the product out of the laboratory and into production is one of the major problem areas in the industry.

The source size can be reduced substantially by using various techniques to shape the source distribution to give more uniform thickness deposition. However, this approach also has its problems. First, because each point on a fixed substrate has a different spatial relationship to an extended source, the homogeneity of the film can vary substantially over the substrate even when its thickness is uniform, especially for reactively deposited films. Second, each source material has different shaping requirements which makes this approach tedious and time consuming. Finally, as the source material erodes away its deposition profile changes, requiring that its source distribution be re-shaped or that it be replaced with a new target, often after only a few percent target utilization.

Various types of substrate motion, when combined with the above techniques for controlling the source distribution, are quite effective in minimizing many of the problems cited above. Mobile planetary substrate fixturing used in the industry is illustrative of this approach. These are typically constant speed mechanisms with one or more degrees of freedom designed to average the source distribution over large substrate areas in a manner that produces more uniform processing. The advantages of reduced source size and improved uniformity that result from substrate motion during the processing are quite significant, assuming that the processing environment is sufficiently clean to assure very pure processing even though the substrate repeatedly moves in and out of the processing area as a consequence of this motion. However, as currently implemented by the PVD equipment industry, these planetaries do no more than average differences in source distributions, such as those due to different source materials and states of erosion. Furthermore, constant speed planetaries are highly inefficient when used for R&D because they are designed for achieving uniform processing over the entire planetary surface, not just selected smaller portions that would be more appropriate for R&D applications.

As a result, no better than 90-95% process uniformity is the current advertised state-of-the-art performance specification for PVD equipment using various combinations of these shaping and averaging techniques, while also maintaining useful product throughputs and source efficiencies.

SUMMARY OF THE INVENTION

The approach to the present invention efficiently and reliably improves on the current state of the art in thin film processing uniformity, especially over substrates of a size comparable to or larger than the source, by providing a technique capable of quickly, accurately, and routinely dealing with the effects of differences and/or changes in various source profiles. The technique is based on the premise that if one has complete knowledge of a source distribution (of any shape), and also has complete control of a mobile substrate fixture (scanner) capable of placing any given point on the substrate at any given position in the source distribution for any period of time, then it should be possible to find a source-substrate motion scenario that produces arbitrarily high uniformity processing over substrate areas of arbitrary size. For a time-independent source distribution (i.e., constant processing rate), a time-varying motion scenario of the substrate relative to the source is

typically required. Alternatively, a constant speed motion scenerio might be combined with a time-varying source distribution to achieve the same final processing profile. The actual motion scenario and/or time varying processing rates used during a given process are determined by the corresponding uniformity requirements.

The above premise is implemented in one illustrative embodiment of the invention using a horizontal flat-plate planetary substrate fixture as shown in FIG. 2 (side view) and FIG. 3 (plan view). This planetary has two degrees of freedom: spin rotation of the individual substrate carriers about their centers, as indicated by the arrow A in FIG. 3, and orbital rotation of the main plate holding these carriers about its center, as indicated by arrow B. This means that the center of any substrate carrier can be positioned at any point on its orbit beneath a given source, as shown in FIGS. 2 and 3. For any given orbital position, the spin of the substrate carriers ensures circularly symmetric processing about the center of the substrate carrier. Depending on the horizontal distance between the center of the source and the center of the substrate carrier, a wide and continuous range of spin-averaged substrate processing profiles can be generated. Four specific examples of equal-time processing profiles as a function of center-to-center horizontal distance are shown in FIG. 4 for the actual case of a quartz deposition from an RF magnetron source. Note that when the center-to-center distance is zero, the carrier is centered under the source, and the substrate deposition profile is the source distribution profile discussed above (e.g., FIG. 1). By varying this distance as a nonlinear function of time , a weighted superposition of processing profiles on the substrate is obtained. FIG. 5 is an example of how a weighted superposition can be used to achieve >99% thickness uniformity over a 4-inch diameter substrate, even though the source distribution is highly nonuniform over the same area.

It is important to note that this particular example of a motion scenerio is just one of many possible motion scenarios capable of achieving essentially equivalent thickness uniformity over the same substrate area. It is a feature of the invention that one can choose the best motion scenario for optimizing both processing homogeneity and processing thickness uniformity simultaneously. For instance, a high-speed continuous motion scan is preferred over the stop-and spin scan illustrated in FIG. 5, when deposition homogeneity is a primary consideration (e.g., during reactive depositions). In practice, this requirement must be traded off against the mechanical limitations of the particular scanner system employed.

It should also be noted that in this particular illustrative embodiment of the invention it is assumed that the processing is isotropic (nondirectional), which is typical of sputtering sources. When directionality of the source becomes a factor, such as with ion- or electron-beam sources, uniformity in all processing properties is still obtained as described above whenever the beam from the source is normal with respect to the substrate surface, or even when the beam is not normal if the surface of the substrate is insensitive to the directionality of the beam with respect thereto. Depending on the orientation of grooves, step edges, etc. on the surface of the substrate, the surface may be sensitive to such directionality. If so, a further degree of motion of the substrate with respect to the source must be added, such as radial movement of an orbiting planetary, in order to achieve totally uniform processing. Although more complicated mechanically, a scanner with three degrees of freedom is fully consistent with the hardware approach, operating principles, and high uniformity processing of this invention.

In summary, in the present invention it has been demonstrated both theoretically and experimentally that non-linear motion scenarios of a substrate with respect to a source can be used to produce extremely uniform processing in both thickness and homogeneity over substrate areas of arbitrary size from both directional and nondirectional sources of all types, even when the source distributions are highly nonuniform on the scale of interest.

In spite of this demonstrated capability for producing extremely uniform processing from highly nonuniform source distributions, the commercial usefulness of this processing technique depends upon whether it can also be implemented in a manner consistent with reasonable throughput and efficiency expectations for this type of equipment. The following are brief description of certain key elements of the invention which may be employed to provide reasonable throughput and efficiency, in addition to unprecedented high performance.

a. In-situ Mobile Source Processing Monitor

Precise knowledge of the source distribution is required in order to predict the non-linear motion scenario that is required to achieve processing of specified uniformity over a specified area. Because of changes in source operating conditions and/or characteristics (e.g., amount of target erosion), the source distribution may vary significantly from run to run. Conventional techniques for calibrating (measuring the amplitude and shape) of source distributions, such as stylus measurements of step heights on test substrates, are not in situ and are tedious and time consuming. Commercial quartz crystal real-time deposition monitors are in-situ devices, but must be operated as fixed-point (stationary) monitors because of cumbersome electrical and/or water-cooling interfaces. In the present invention, a commercially available quartz crystal monitor has been custom modified for mobile operation and incorporated directly onto the scanner. Custom-designed control electronics for this monitor provide an efficient interface for optionally computer controlled amplitude and shape calibration of any source (except heaters, which require a separate mobile thermal processing monitor) just prior to substrate processing. This quick (<1 minute) and accurate way of updating the source distribution in a timely manner is an important feature in its own right, especially compared to the current alternatives which are not in situ and take hours to generate equivalent information. The monitor of the present invention is equally effective in measuring etch rates and profiles generated by a collimated ion-beam source. This feature alone provides the capability of efficiently combining in one system the full capabilities of different sources as indicated in FIG. 2 that traditionally have been kept separated. In addition to the obvious cost savings, this combination of capabilities in one system opens the door to certain kinds of substrate processing that were previously unattainable. Note that in measuring etch rates as opposed to deposition rates, the quartz crystal sensor must be precoated with the material of interest. The availability of a variety of deposition sources in the same vacuum system with the ion-beam etching source makes this precoating requirement both simple and quick, and the corresponding etch rate measurements

are very accurate. This is to be contrasted with the traditional method of characterizing ion-beam sources that uses a Faraday cup to measure the ion-beam current. This method is clearly less satisfactory because the ion-beam current is only indirectly related to the actual etch rates of the various materials of interest, and is insensitive to the presence of high-energy neutral atoms that also contribute to the etch rate. However, a mobile Faraday cup ion-beam current monitor has also been incorporated into the present invention because of its complementary measurement capabilities. The importance of this mobile in-situ quartz monitor to the efficiency of the present invention cannot be overstated. Although it is often possible to implement the processing technique of this invention without relying heavily on this in-situ monitor (e.g., some pure metal sources have fairly constant deposition profiles), its presence vastly enhances efficiency and simplifies operations even for these special cases. For processing where the source distributions often vary substantially from run to run (e.g., reactive sputtering or ion-beam milling), the presence of this in-situ monitor is indispensable to achieving useful commercial throughputs using this processing technique. In addition, the existence of this monitor in a multi-source system enormously simplifies establishing the absolute deposition rates of the various sources, which typically must be frequently updated. Although a quartz crystal monitor is not an absolute processing monitor because its response varies as a function of crystal life, its relative response to processing from different sources is not a function of crystal life, at least to first order. Given that the relative crystal response of the mobile monitor to processing from all the different sources of interest has been measured once, measuring the absolute processing rate of just one source provides an absolute calibration update of the quartz monitor for all sources. This is to be constrasted with the traditional approach of using dedicated fixed point quartz monitors for each source, where the relative response to different source processing is irrelevant, and absolute deposition rate updates must be carried out for each monitor-source pair. Finally, it is clear that this particular aspect of the invention has considerable stand-alone significance. The need for a quick and accurate method of measuring the shape and amplitude of source distributions in situ is a universal need throughout the PVD equipment industry. A stand-alone unit consisting of a quartz monitor, scanning mechanism, vacuum feedthroughs, readout electronics, and dedicated computer controller and data acquisition system is thus a futher important aspect of this invention.

b. Process Control

The in-situ processing monitor carries out the source calibration just prior to, rather than during, the substrate processing. This is necessary because usefully placed real-time processing monitors significantly obstruct the source distribution, especially when the substrates are of a size comparable to or larger than the source distribution. Therefore, the effectiveness of the processing technique of this invention depends directly on how similar the source distribution is during substrate processing to what it was during calibration. To achieve this required similarity, at a minimum the total processing environment must be precisely and reproducibly controlled thoughout the entire processing procedure. A controlled processing environment is a necessity for the useful operation of any PVD system. However, since this invention offers substantial improvements over the prior state of the art in processing uniformity, the necessity for corresponding improvements in the control of the processing environment are to be expected. In this invention no new technology has been introduced for achieving enhanced process control. Rather, considerable care and attention to detail has been exercised in the choice and operation of commercially available pressure and source controllers. The one possible exception is the use of a custom-designed passively-controlled high-purity gas feed system, which provides an ideal combination of performance, versatitility, and reliability within the context of the current implementation of the invention.

c. Precision Scanner

A precision motion mechanism is required for quickly, accurately, and reproducibly positioning the substrates and mobile source monitors relative to any given source distribution in order to successfully implement the invention. The more rapid the motion of this mechanism, the higher the quality of processing in every respect (e.g., deposition homogeneity and substrate throughput). The current implementation is a planetary system with two independent degrees of freedom (orbit and spin) with reproducible orbital positioning accuracy better than 0.010-inches. This is a higher performance version (e.g., higher precision bearings, higher tolerance parts) of conventional flat-plate planetary fixtures that are commercially available, and is just one possible implementation of any number of possible motion mechanisms for changing the source-substrate relative postitioning (including moving the source). In any case, for any given process, the required positioning accuracy depends on the specified uniformity requirements.

d. Computer Control, Data Acquistion and Analysis

The computation time involved in calculating the scanner motion required to achieve processing of any specified uniformity over any specified area from any given source distribution is formidable. Only with the advent of the most recent generation of portable instrument control computers has it been possible to meet such a requirement in a practical way on the time scale of interest. A second feature of these high-speed computers is enhanced processing reliability. A problem with any computer-controlled process operating in an industrial environment is electrical-noise induced processing errors. Processing reliability is of particular importance in this invention, where errors in the sophisticated and high-speed planetary motion might easily go unnoticed, even by a perceptive observer. A high-speed computer provides the luxury of at least double-checking most commands before proceding.

e. Efficient, Mobile, Front-side Heater

A mobile radiative heater is important to the overall success of thin film processing systems of the present invention, since in many applications there is a need to heat substrates under vacuum over a wide temperature range (100°–600° C.) just prior to or during the processing of thin films. The present invention incorporates a front-side radiative heater of uniquely high mobility that permits the uninhibited operation of the rest of the system without asking the user to do without a real-time heater. The keys to this aspect of the invention are the

use of material with a strong temperature coefficient of resistance for the heating element and the mounting of the heater onto the rotary shutter (FIG. 2). A strong temperature coefficient makes it possible to simultaneously use the heating element as the sensor for monitoring the heater temperature. In addition, by using a constant-voltage, current-limited power supply as the source controller for positive coefficient heating elements (vice-versa for negative coefficient heating elements), a significant degree of temperature regulation is also achieved. Thus, only one high-vacuum electrically-insulated feedthrough is required to power, monitor, and regulate this implementation of a radiative heater, which may be a thick-film platinum resistor patterned onto an insulating ceramic substrate. It is this aspect of the heater design that makes possible its phenomenal mobility within a high-vaccum chamber. In the present invention there is the capability for rapidly oscillating the substrate carriers between any two sources, so that heating during processing can be readily achieved in this manner, where the heat source is preferably adjacent to the processing source of simultaneous interest. Since the system may have five or more processing sources, a highly mobile heater is required in order to satisfy the processing requirement that the heater be adjacent to the processing source of interest whenever sequential preheating or heating during the processing is required. This is accomplished by mounting the heater on the rotary shutter, and using a sliding electrical contact positioned on the axis of rotation of the shutter as the electrical interface between the heater and its power supply. Finally, the mobile front-side radiative heater as implemented in this invention is extremely efficient, in that most of its energy couples directly into the substrate and not to the surroundings. This is in direct contrast with most commerically available radiative heater implementations (e.g., quartz-tube radiative heaters), where coupling efficiencies are often so low that the maximum allowable substrate temperatures are dictated by the temperature limitations of the surroundings.

f. Mobile Substrate Carrier Heat Sinks

In many applications there is a need to heat sink the substrates in order to stabilize the processing temperatures. The conventional approach of using water-cooled the substrate carrier is incompatible with the current implementation of this invention where the substrates must be extremely mobile. Various phase-change materials with high heats of transformation have been incorporated into the substrate carriers of the present invention in order to provide a wide range of stable processing temperatures without restricting carrier mobility. For example, calcium chloride hexahydrate sealed into an aluminum or stainless steel substrate carrier provides an effective 27° C. mobile substrate heat sink for use in this invention.

The significance of the processing techniques of the present invention are summarized below:

a. High quality thin film processing with uniformities exceeding 99% are now possible without significant compromises in throughput. Relevant applications for this unprecedented uniformity include the fabrication of optical and magnetic memory disk storage media, active and passive semiconductor devices (particularly on large monolithic circuits), and passive electrical components for hybrid integrated circuits. Device reproducibility resulting from very uniform processing over large substrate areas improves yield and can eliminate the need for time consuming and expensive trimming operations that are currently often required. Similarly, compositional uniformity is a key requirement in the production of reproducible and stable thin-film resistors. Although not as common a processing requirement, the prescribed nonuniformity capability of this invention is also quite significant. An example of an application where a thin-film processing of specified nonuniformity would be useful is in the fabrication of spatially-varying optical elements, such as apodizing filters.

b. A wide variety of small, high-performance PVD sources can be combined on the same PVD system to provide unprecendented versatility and capability within the same system. Since the source distributions may be continuously updated, the type and design of the sources are not critical and extremely high target utilization is routinely achieved. Relevant applications for the simultaneous use of different types of sources on PVD systems includes planarization of coatings on highly structured substrate surfaces by combining the step-coverage properties of magnetron sputtering with the highly directional etching properties of a variable angle-of-incidence ion-beam source focused onto a rotating substrate. Similarly, the ion-beam source may be used to carry out dry-etch pattern delineation on hygroscopic materials, which may then be hermetically sealed without breaking vacuum with a conformal sputtered thin-film protective layer.

c. R&D activities can be carried out with great efficiency, and then scaled up to production-size substrates (up to 8-inches in diameter in the current configuration) without changing sources or fixturing. This is because the areas of high-uniformity processing can be tailored to match the substrate size and uniformity requirements of any give processing task simply by programming the computer accordingly. In this way, the approach of the present invention can be used to efficiently and painlessly bridge the gap between initial fabrication of one-of-a-kind R&D devices and the production of the same devices at useful commercial throughputs.

Other advantages and applications of this invention will be apparent from a reading of the following specification and claims taken with the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram of a typical PVD source illustrating the deposition profile thereof.

FIG. 2 is a diagrammatic side view of an illustrative PUD system in accordance with the invention.

FIG. 3 is a plan view of the orbiting planetary substrate fixture of FIG. 2.

FIG. 4 illustrates a set of hypothetical processing profiles.

FIG. 5 illustrates an optimized set of hypothetical deposition profiles, including the total (combined) deposition profile.

FIG. 6 is a functional hardware block diagram of an overall illustrative system in accordance with the invention.

FIG. 7 is a component hardware block diagram of an illustrative embodiment of the overall system of FIG. 6.

FIG. 8 is a cross-sectional view of an illustrative phase-change substrate carrier in accordance with the invention.

FIG. 9 is a diagrammatic illustration of an illustrative mounting of an ion-beam source inclined at an angle

with respect to the axis of rotation of a spinning substrate carrier.

FIG. **10** is a diagrammatic illustration of an illustrative mounting of a crossed-beam fixture for simultaneous secondary-ion deposition and ion-beam scrubbing on an orbiting and/or spinning substrate.

FIG. **11** is a plan view of an illustrative rotary shutter including the heater of FIG. **12**.

FIG. **12** is a plan view of an illustrative substrate heater in accordance with the invention.

FIG. **13** is a flow chart of an illustrative overall operation of the system of FIGS. **6** and **7**.

FIG. **14** is a plan view of an illustrative dual substrate (pair) processing in accordance with the invention.

FIG. **15** is a flow diagram of an illustrative source distribution shape calibration program for use in the operation of FIG. **13**.

FIG. **16** is a flow diagram of an illustrative source calibration program for correlating source peak deposition rates to respective source electrical inputs for use in the operation of FIG. **13**.

FIG. **17** is a graph of illustrative profiling data obtained in accordance with the program of FIG. **15**.

FIG. **18** is a graph illustrating the source profile corresponding to the data of FIG. **17**.

FIG. **19** is a flow diagram of a program for effecting an illustrative source/planet model in accordance with the source/planet modeling routine of FIG. **13**.

FIG. **20** is a flow chart of a program for effecting an illustrative scan optimization in accordance with the scan optimization routine of FIG. **13**.

FIG. **21** is a flow diagram of a program for effecting computations of the processing parameters in accordance with the computation of processing parameters routine of FIG. **13**.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT OF THE INVENTION

Reference should be made to the drawing where like reference numerals refer to like parts.

FIG. **6** is a high-level block diagram of the basic component hardware of the invention. The hardware block diagram shown in FIG. **6** is high-level in the sense that each block represents a functional hardware subsystem. Each hardware subsystem is typically composed of several separate hardware components that operate synergistically, as will be further described below with respect to FIG. **7**.

In general, the system of FIGS. **6** and **7** include a vacuum deposition subsystem, which is required to provide a stable and controlled environment for the reproducible fabrication of thin film structures and devices. This vacuum subsystem consists of a vacuum deposition chamber **10** and includes all the pumps, valves, and feedthroughs **100** (FIG. **7**) required to produce a low background pressure (<1E-7 Torr) in the chamber, such accessories being known to those skilled in this art. Vacuum subsystems suitable for implementing the present invention are commercially available from a variety of different vendors (e.g., Varian Associates, Torr-Vacuum Products) in either component or assembled form, as desired.

The system also includes a pressure controller subsystem **12** (FIG. **6**), which consists of all those components (e.g., control valves, gas feed systems, pressure sensors, etc.) necessary to stably and reproducibly set, measure, and control the gas background in the vacuum chamber during processing. A suitable active feedback controller subsystem of this type is commercially available from MKS Instruments Corporation. However, in the present invention where many different types of sources may be employed simultaneously, it is usually necessary to introduce and control mixtures of several different high purity gases over a very wide range of pressures. Since most commercially available active pressure controllers are narrow range devices, several of them would therefore be required. In this instance, the system may preferably employ a custom-designed passive pressure controller, there being provided at least one or more (three are preferred) regulated supply channels of inert and/or reactive gas **106** (FIG. **7**), where each of these channels has typically three separate feeds **110** to vacuum chamber **10**, the three feeds typically being respectively associated with the various types of sources which may be individually or jointly used in the system. These sources are typically one or more DC and/or RF sputter sources, one or more ion-beam sources, a heat source, and one or more auxiliary sources such as an evaporation source, etc. (FIG. **2**). Each of these sources typically requires different pressure levels in the chamber and thus each feed line includes a needle valve **114** for pressure adjustment over a range of typically 1E-1 to 1E-6 Torr. Each feed also includes a on-off solenoid valve **116** for feed line selection and chamber isolation. Another solenoid valve **115** may be employed for purging the channel between feed selections. All solenoid valve operations are remotely programmable via the multiprogrammer computer interface **105** discussed below. Measurements of the chamber pressure may be effected with a complementary combination of pressure gauges **101** and **118** and corresponding control electronics **102** and **119**, as shown in FIG. **7**, such as MKS model **390** absolute capacitance manometer and model 270B controller, and Granville-Phillips model UPC-303 ion and thermocouple gauge pressure measurement system. Note that the Granville-Phillips model UPC-303 also serves as the automatic controllers **102** for the pumps and valves **100** of the vacuum subsystem **10**.

The orbiting planetary substrate fixture **16** is a precision in-situ motion mechanism which quickly, accurately, and reproducibly positions the substrates and mobile source monitors relative to any given source distribution in order to successfully implement the present invention. This planetary may comprise a horizontal, 24-inch nominal diameter, flat plate planetary with independent orbit and spin motions of up to ten 4.5-inch diameter planets (substrate carriers), as shown in FIGS. **2** and **3**. Electrically isolated substrate carriers provide for DC/RF bias and etch capability. Easily adjustable source-to-substrate distance accommodates substrates over 1-inch thick, and allows for custom-designed substrate carriers, such as the phase-change carriers described below. Such a planetary is commercially available (e.g., Torr-Vacuum Products), although an upgraded version that utilizes precision bearings and higher tolerance components is preferred for the present invention.

One or more substrate carriers **15** are provided on the orbiting planetary substrate fixture **16**, each substrate **14** being disposed on the substrate carriers **15**, as shown in FIGS. **3**, **6**, and **7**. The substrate carriers **15** may contain a high heat-of-fusion phase-change material in order to provide a stable heat sink for the substrate during processing, as required. Such an approach to heat sinking in this embodiment of the invention is preferred because

the conventional approach of using water-cooled substrate carriers is incompatible with the requirement that the substrate carriers be highly mobile. Any number of phase-change materials with a wide range of transition temperatures might be used, including metals, alloys, and organic and inorganic compounds. For this application, the final choice is dictated primarily by considerations of transition temperatures; heat of fusion per unit volume; safety in handling, containment, and operation; and stability and reliability in phase-change properties (e.g., minimal supercooling and/or superheating effects). Based on these considerations, the phase-change material may be any one of a variety of salt hydrates, including calcium, sodium, and magnesium. One specific implementation may be calcium chloride hexahydrate **148** (containing nucleators to suppress supercooling) sealed in a stainless steel or aluminum enclosure **150** with a machined interior **149** to improve the thermal conductivity between the phase-change material and its enclosure, as shown in FIG. **8**. Calcium chloride hexahydrate has a 27° C. melting point, 1.6 specific gravity, and 46 calories per gram heat of fusion. These properties make it ideally suited for providing a mobile, compact, lightweight, stable, reliable, and effective low temperature heat sink for even high power processing. For instance, 500 grams of this material sealed in a 4.5-inch diameter by 1.5-inch high aluminum container weighs less than 750 grams total, but will absorb over 20 watts continous power input for up to one hour without completing its phase change at 27° C.

Rotary shutter **32** (FIG. **7**) may comprise a 22-inch diameter electropolished stainless steel plate internally suspended from a central clutch bearing (not shown). Planetary orbital motion may be used to position the shutter, thus eliminating the need for a separate actuator, position indicator, computer interface, and high-vacuum rotary feedthrough. The shutter provides additional substrate protection from particulate contamination, serves as the carrier for the mobile front-side radiative substrate heater, and may be used to select individual substrates for DC/RF bias/etch sputtering. Shutters of this general type (using external actuators) are commercially available from Torr-Vacuum Products.

Planetary controllers **26** (FIG. **6**) provides the means for accurately setting planetary position and/or controlling planetary speed and direction at any given time. It also provides real-time monitoring of these parameters directly to the computer system **28** (FIG. **6**). Thus, an unlimited number of planetary motion scenarios are at the user's disposal through the computer software. The controller may be a programmable dual channel power supply **140** (e.g., Hewlett-Packard model **6205C**) which controls two reversible variable speed motors **142** and **144** used to independently drive the orbit and spin motions, respectively, as shown in FIG. **7**. Orbital position may be precisely monitored with an absolute position optical shaft encoder **146** (e.g., BEI series M-25). Front panel switches and status indicators also allow complete manual control, if desired.

The computer system **28** (FIG. **6**) is the nerve center of the physical vapor deposition system of the present invention. Although manual overrides are available and the computer system need not be used, in practice it is almost indispensible for all but the simplest processing. It consists of all the software and the computer related hardware and interfaces necessary to set, control, monitor, and document the rest of the system hardware. This includes the user interface (keyboard and/or touchscreen), central processing unit, disk mass storage, CRT monitor, printer, and various control and data acquisition interfaces (e.g., HPIB, GPIO, RS-232, multiprogrammer) necessary to communicate with the assorted programmable hardware components that comprise much of the remainder of the PVD system. The computer of the system may be a Hewlett-Packard 9000 model 310, which is a bundled measurement automation system consisting of: 98561A SPU; 35731A CRT monitor; 46020A keyboard; Basic 5.0; 1 Mbyte RAM; HPIB, GPIO, RS-232, and HP-HIL; touch-screen bezel; and battery-backed real-time clock. The disk drive may be a Hewlett-Packard model 9153A, which combines the storage (10 Mbyte) and speed of a hard disk with the backup and interchange capabilities of $3\frac{1}{2}$-inch microfloppies (780 Kbyte) into a single compact package. The printer may be a 150 cps Hewlett-Packard model 2225A. The multiprogrammer may be a Hewlett-Packard model 6940B, which provides the various required A/D and D/A interfaces, as well as an expandable card-cage design that makes it suitable for a wide range of high-speed automatic test, data acquisition, and control applications, as needed.

As stated above, the source(s) **18** (FIG. **6**) may be any of a number of different types of sources such as DC/RF magnetron, diode, and triode sputtering sources; resistive and E-beam thermal evaporation sources; ion-beam milling and secondary-ion deposition sources; and radiative heater sources; where, in the present preferred embodiment, the sources are shown mounted either on the top plate of the vacuum deposition chamber or on the rotary shutter (FIG. **2**). This deposit-down configuration is an arbitrary choice with respect to the implementation of the invention, and most other configurations, including deposit-up and side-deposit, are equally acceptable in this regard. The primary requirement on each source for the successful implementation of the processing technique of the present invention is that the source distribution be sufficiently stable and independent of the properties of the substrate that its processing properties can be fully characterized or predicted from the shape and amplitude of this destribution. Even if the substrate properties influence the processing properties of the source, it is often still possible to systematically predict and/or experimentally measure these interactions and to make the appropriate and compensating corrections to the processing parameters. For example, the effect of substrate temperature on deposition rate can be dealt with easily. Each source (except for the heater) is hermetically secured in a known manner to one of the ports in the top plate of the vacuum chamber, as shown in FIG. **2**. A specific DC/RF sputtering source **120** (FIG. **7**) which may be employed is Sputtered Films Inc. model PSG-3. The corresponding DC power supply **122** may be Sputtered Films Inc. model 600-4.5. The corresponding RF power supply **124** and matching network **126** may be RF Plasma Products models RF-10 and AM-10, respectively. As an on source **128**, Ion Tech model 3-1500-250 may be employed, using Ion Tech model MPS-3000FC as the corresponding power supply **130**. Fixtures **121** at user specified angles of incidence ranging from **0** to **50** degrees relative to the axis of rotation of the spinning substrates **15** may be provided, as shown in FIG. **9**. The processing chamber may also accept a second ion gun, either in a fifth top-plate port or on an optional crossed-beam fixture **123** designed for ion-beam scrubbing of substrates during secondary-ion deposition, as shown in

FIG. 10, where the secondary-ion deposition is effected by ion-beam bombarding a source material 193 onto a substrate 14.

A front-side radiative heater 30 may be mounted on a planetary shutter 32 to permit mobile front-side heating of substrates prior to and/or during subsequent processing (FIG. 7). A plan view of a rotary shutter 32 is shown in FIG. 11, where the heater 30 may be positioned adjacent to the open portion 158 of the shutter. Since the open portion of the shutter is always aligned with the current processing source 18 (FIG. 6), this configuration assures that the heater is always adjacent to the source of current interest, and thus, that sequential heating of substrates prior to or during the processing is easily implemented, as discussed above. A slot 160 (FIG. 11) may be provided in the shutter 32 through which a single insulated electrical lead 162 connects the heater 30 with a sliding contact electrical connector 152 (FIG. 7) that may be similar to the ones used for the mobile deposition monitors discussed below. Only one insulated lead is required if the heater has a large temperature coefficient of resistance, since in this instance the heater may be simultaneously operated as the heating element, temperature sensor, and temperature controller, as discussed above. The heating element may comprise a nominal 10 ohm thick-film platinum resistance radiative heater 155 which is silk-screened patterned and then fired at >1100° C. onto one side of a 4.5-inch diameter by 0.04-inch thick alumina or BeO ceramic substrate 153, as shown in FIG. 12. An insulating overglaze may be coated over the entire heater pattern (except for the live contact pad 154 and the ground contact pad 156) and then fired at >900° C. Heater temperatures over 600° C. at supply powers (100 watts may be achieved with +/−1% reproducibility. An appropriate constant-voltage, current-limited power supply 138(FIG. 7) may be a Kepco model JQE 55-2M.

The remotely programmable source power supplies 122, 124, 130, and 138 of FIG. 7 are included in the source controller 20 of FIG. 6. By "remotely programmable" is meant that, with a suitable control and/or data acquisition interface to the computer 103, the programmable device can be remotely operated by the computer. Suitable interfaces for effecting communications between the computer and the power supplies, as well as with all of the other programmable components and subsystems of the invention (e.g., the vacuum and pressure controllers) may include standard GPIO, HPIB, and RS-232 interfaces (104, 99, and 129, respectively, in FIG. 7) and a multiprogrammer 105 that may contain various A/D and D/A convertors for controlling and/or monitoring several processes at once. Alternatively, local programming may be selectively employed at the user's disgression to achieve controlled operation at the component or subsystem level. Generally, source controller 20 (FIG. 6) includes a combination of remotely and/or locally programmable power supplies and feedback monitors necessary to set and control the electrical parameters applied to a given source during the processing. For example, in DC supply 122 (FIG. 7), the current delivered to the source is internally controlled by a feedback loop to thus control the amplitude (rate) of the source distribution. Therefore, the effectiveness of these control techniques in achieving uniform depositions depends strongly upon the reproducibility and stability of the processing environment, as discussed above.

Mobile source processing monitors 22 are provided on the orbiting planetary substrate fixture 16 (FIG. 6). These monitors are used in calibrating (establishing the amplitude and shape) the various sources 18, as needed, just prior to substrate processing. These monitors may include a thermal deposition monitor 134, an ion-beam current deposition monitor 132, and a mass-sensitive deposition monitor 133, as shown in FIG. 7. The primary requirements on these monitors are that they be in situ, real-time, and mobile; and that they provide sufficiently accurate calibration information on the various source distributions that it is possible to achieve the desired levels of substrate processing uniformity. The thermal deposition monitor may comprise a resistance thermometer (e.g., a thick-film platinum resistance thermometer on a 1-inch square ceramic substrate commericially available from Johnson Matthey Inc.) or a thermocouple (e.g., a stainless-steel-sheathed type-K thermocouple available from Omega Engineering attached to a 1-inch diameter by 0.005-inch thick stainless steel sensor plate). The ion-beam current monitor may comprise a Faraday cup. The mass-sensitive monitor may comprise a quartz crystal sensor, such as Inficon model 007-215, with appropriate modifications to its thermal and electrical interfaces in order to improve mobility, as described below. Each of these monitors preferably utilizes a sliding contact electrical interface 152 (FIG. 7) between moving and non-moving portions to allow for maximum mobility. A suitable in-situ coaxial sliding electrical contact may be obtained from Suhner (e.g., subminiature bayonet connector model SMS). Alternatively, a rotating electrical feedthrough may be utilized and the sliding electrical contacts implemented external to the vacuum chamber in a manner known to those skilled in this art. The quartz crystal monitor also requires a thermal interface to maintain its operating temperature between 0° and 50° C. for highest reliability operation. Commercially available quartz crystal monitors are designed to operate as fixed-point sensors, and utilize cumbersome water cooling lines to satisfy this thermal interface requirement. In the present embodiment of this invention the need for water lines has been eliminated by providing a strong thermal link between the quartz crystal monitor 133 and the massive, and therefore high heat capacity, orbiting planetary substrate fixture 16 (FIG. 7). The overall temperature rise of the combined monitor-planetary thermal system is miniscule on the scale of interest, particularly since the quartz crystal monitor is typically used intermittently in the present invention, rather than continuously as in most fixed-point applications. The means for achieving an effective thermal link involves the straightforward use of thermal gaskets and straps, and is well known to those skilled in this art. At very high deposition rates (e.g., ion-beam milling), masks that stop down the crystal field of view of the source may be used to further ensure acceptable operating temperatures, since at high deposition rates the reduced sensitivity of a stopped-down quartz crystal monitor is insignificant.

Source monitor controllers 24 (FIG. 6) are commercially available for each of the above processing monitors (e.g., Omega Engineering thermocouple controller model 402B. Ion Tech power supply and ion-beam current monitor controller model MPS-3000FC, and Inficon quartz crystal controller model XTC). However, commercially available quartz crystal monitor controllers are designed for conventional fixed-point operation and are not well-designed for mobile applica-

tions. For instance, the loss of a single data point during calibration in the present invention is much more serious than for fixed-point monitoring. On the other hand, many of the design features of the commercial units (e.g., soak times, set points, rate ramps, etc.) are of no use in mobile applications. Therefore, a preferred embodiment for the present invention is a custom quartz crystal controller that is designed for mobile calibrations and rapid computer data analysis of calibration data. Specifically, a controller with these properties that takes direct advantage of the powerful control computer may be efficiently implemented by utilizing in an appropriate manner the standard pulse counting, time and frequency reference, and breadboard cards available with the Hewlett-Packard multiprogrammer model 6940B. The output of this controller is simply the mass-dependent quartz crystal resonant frequency. Therefore, the efficient operation of this quartz crystal controller in the present invention is primarily a result of developing and implementing the corresponding control software to interpret changes in this resonant frequency in terms of the calibration parameters of interest, as described below. Using the powerful system control computer directly for acquisition and analysis of the quartz crystal monitor raw data offers special advantages relative to commercial controllers, including programming options to distinguish "good" from "bad" data points, take special averages, store and compare data, perform interpolations and curve fittings, etc.

FIG. **13** is a functional flow diagram of the processing technique of the present invention where the program is executed by computer system **28** (FIG. 6). For symbolic clarity, operator inputs are ellipses, operator decisions are diamonds, and computer-controlled hardware/software operations are rectangles. The following are explanations of each of these components within the context of this flow diagram.

Operator Inputs

The required operator inputs for any given processing task are limited to specifying at the appropriate points in this flow diagram just a few major process parameters; namely:

a. Source type and position (ellipse **34**);

b. Planetary mode (ellipse **36**);

c. Processing area and uniformity (ellipse **38**);

d. Substrate positions on the planetary (ellipse **40**); and

e. Processing rate and thickness (ellipse **42**).

The preferred embodiment of the invention offers several planetary mode processing options, including continuous, sequential, pair, and two-source processing planetary modes. A pair processing mode is illustrated in FIG. **14** by a plan view of the shutter-planetary system, where the source distribution **173** is diagrammatically shown centered in the shutter opening **158** (FIG. **11**). The pair of substrate carriers **15***a* and **15***b* are scanned non-linearly in an oscillatory fashion in front of the source to simultaneously effect uniform processing thereon.

Note that once a processing task or series of deposition tasks have been defined in the above manner, they may be stored and then repeated in the future as desired, where the only user input required at that time is to load and document the positions of the substrates on the planetary. For clarity, this particular option is not shown in the functional flow diagram of FIG. **13**.

Operator Decisions

Only one operator logistic decision, as indicated at diamond **44** (FIG. **13**), is required in defining the specifics of a processing task within any processing task sequence: does the source distribution need recalibration?The factors involved in deciding whether or not to recalibrate are as follows. In the preferred embodiment of the invention, the source monitor carries out the source calibration just prior to, rather than during, the substrate processing. This is because usefully placed real-time processing monitors significantly obstruct the source distribution, especially when the substrates are of a size comparable to or larger than the source distribution. Therefore, the effectiveness of the present invention in achieving a uniform substrate processing depends directly on how similar the source distribution during the processing is to what it was during calibration. To achieve the required degree of similarity in source distributions, it is essential at a minimum that the pressure and source controllers **12** and **20** (FIG. 6) precisely reproduce the same processing environment during substrate processing that was used during source calibration. In fact, the ability to precisely reproduce and maintain the total processing environment is an important feature of the present invention, where considerable care and attention to detail have been exercised in the selection and operation of the hardware components necessary to achieve this processing requirement. However, the source distribution can also depend on the state of erosion of the source material, which introduces inherent use-dependent variations of the source distribution, even when the processing environment is held constant. Therefore, the need and frequency of source recalibrations are determined at a minimum by this inherent variation of the source distribution and its effect on the specified uniformity requirements. For most applications, this use-dependent variation is extremely small within a given processing task, but can become quite significant after several runs. It is a unique feature of the present invention that total source recalibration can be quickly (<3 minutes) and efficiently carried out just prior to every processing task, if necessary, thus elminating all slowly varying (on the time scale of a given task) use-dependent changes in the source distribution as significant sources of error.

Computer-controlled Hardware/Software Operations

There are five computer-controller hardware/software operations illustrated in the functional flow diagram shown in FIG. **13**. Although these operations occur automatically as needed, they can be accessed individually as required to provide the following standalone operations.

a. Source calibration is effected at block **50**. This program controls the planetary motion, data acquisition, and data analysis necessary to establish the deposit, etch, thermal, and/or electrical shapes of each source distribution using the various/mobile source monitors. This routine also carries out the curve fitting necessary to directly and continuously relate the source peak rate (amplitude) to the respective source power supply settings, as will be further discussed below.

b. Source/planet modeling is effected at block **52**. Given any source distribution and planetary configuration, this program calculates a complete set of hypothetical processing profiles as a function of source-substrate relative positioning. These processing profiles serve as

the building blocks for the motion scenario optimization program defined below.

c. Motion scenario optimization is effected at block 54. For a given planetary mode, this program uses the previously calculated processing profiles to establish the optimum set of planetary motion parameters (relative positions, speeds, directions, and times) required to produce processing of specified uniformity over a specified area. Note that "uniformity" is again used here in the broadest sense to means uniformity in all properties, not just thickness. This is an important distinction, since it is often possible to achieve the same processing uniformity over a given processing area using any one of several different motion scenarios. It is the processing homogeneity requirement that is used to distinguish between these different motion scenarios.

d. Computation of processing parameters is effected at block 56. For any given motion scenario and choice of substrate positions on the planetary, this program calculates the processing parameters (absolute positions, processing times, pressure settings, power supply settings, etc.) required to achieve processing of specified thickness at a specified peak processing rate, as selected by the operator (input 42, FIG. 13).

e. Planetary/processing control and process documentation are effected at block 58. This routine provides precise and fail-safe control of planetary motion and the processing environment, as determined by the motion and processing parameters established above. It also provides real-time (CRT) documentation of all aspects of the processing during the run, including motion parameters, motion scenario status, source parameters, and total system status. A concise and comprehensive hardcopy summary is provided at the end of the run.

Each of these hardware/software operations may be combined into one completely automatic operation using the next level of software control. If desired, this next level of software control may also encompass total "one-button" computer-controller processing (i.e., computer-controlled pumpdown, process gas selection and control, source selection, power supply settings and control, etc.)

Having briefly described the computer-controlled hardware/software operations 50, 52, 54, 56, and 58 (FIG. 13), certain ones will now be discussed in further detail with the aid of specific examples. In particular, it is assumed in the following discussion that source 120 (FIG. 7) is operated as a DC sputtering source controlled by OC power supply 122. Since all of the other possible sources and supplies are operated in a substantially similar manner in the invention, the use of this specific example in no way restricts the generality of this discussion.

Referring to FIG. 13, the decision to calibrate the source is made at block 44. Calibration involves establishing both the shape and amplitude of the source distribution using the procedures illustrated in FIGS. 15 and 16.

Referring to FIG. 15, the procedure for calibrating the shape of the source distribution consists of the following steps. Block 501 involves turning on the source using power supply settings appropriate to the deposition rate of interest. (The power supply settings are not critical, since the shape of the source distribution is usually independent of deposition rate, at least to first order.) Block 502 involves moving the deposition monitor to an appropriate initial position at the edge of the source distribution. In block 503 the deposition rate measured by the deposition monitor is recorded. Block 504 consists of incrementing the monitor position a specified amount (pre-determined by the curve fitting accuracy requirements). In block 505 the monitor position is checked to see if the shape-calibration data acquisition has been completed, i.e., if the deposition monitor has completely scanned the source distribution. If not, the procedure loops back to block 503 and another data point is recorded. When data acquisition has been completed the data is plotted, as indicated in block 506. An example of such a plot is shown in FIG. 17. As indicated by block 507, the shape calibration program also effects the curve fitting necessary to store the source distribution shape in parametric form for use later in the flow diagram of FIG. 13. FIG. 18 shows the curve fit to the data of FIG. 17. As part of the curve fitting routine, the true center of the source distribution is determined, since this, rather than the source geometric center, is the nominal source position of interest.

The procedure for calibrating the peak amplitude (deposition rate) of the source distribution as a function of power supply settings is illustrated in FIG. 16. In this instance, the deposition monitor is first positioned at the true center of the source distribution, as indicated by block 511. The source is then turned on using a specific power supply setting at the lower end of the range of interest, as indicated by blocks 512 and 513, respectively. In the present example of a DC sputtering source, this involves setting the power supply current. As indicated by block 514, all relevant power supply electrical outputs are recorded at this time, including current, voltage, and/or power. The deposition rate measured by the deposition monitor is then recorded, as indicated by block 515. At this point the power supply current setting is incremented a pre-determined amount (as established by the curve fitting accuracy requirements), and then checked to see if it is still in the calibration range of interest, as indicated by blocks 516 and 517, respectively. If so, the procedure loops back to block 514 and another set of data is recorded for this new current setting. When the amplitude calibration has been completed, the data is plotted (block 518), curve fitted (block 519), and then stored in parametric form for use later in the flow diagram of FIG. 13.

Referring to block 52 of FIG. 13, the source/planet modeling program uses the source distribution determined by the source calibration program (block 50) to calculate a complete set of hypothetical deposition profiles as a function of source-substrate relative positioning. This procedure is illustrated in more detail in FIG. 19, where the source distribution amplitude and shape are read in at block 521. Block 522 is a program initialization step, and involves setting the hypothetical source-to-substrate center-to-center distance to zero. Block 523 is a similar initialization step, and involves setting the hypothetical substrate annulus radius to zero. That portion of the source distribution that overlaps a substrate annulus of specified radius at a specified source-to-substrate distance is then averaged over the area of this annulus, as indicated by block 524. (In reality, this averaging occurs because the substrate is spinning relative to the source.) The radius of the substrate annulus is then incremented (block 525) in a manner consistent with the substrate diameter (block 526) until a hypothetical substrate deposition profile (thickness versus substrate radius) is obtained and stored for the specified source-to-substrate distance (block 527). The

source-to-substrate distance is then incremented (block **528**) over all distances where there may be significant substrate depositions (block **529**) to finally obtain a complete set of hypothetical deposition profiles. Specific examples of four such hypothetical substrate deposition profiles were shown in FIG. 4 above. In both instances of incrementing distances (blocks **525** and **528**), the increment size is determined by the accuracy requirements for these hypothetical profiles, which are in turn determined by the desired uniformity requirements. The tradeoff is therefore computer computation time versus the ultimate degree of deposition uniformity. In general, enough hypothetical deposition profiles are generated that it is other factors that ultimately limit the deposition uniformity. For the present computer system, this corresponds to computation times of the order of one minute.

Referring to block **54** of FIG. **13**, the scan optimization program utilizes the hypothetical substrate deposition profiles generated in block **52** as building blocks in selecting and weighting an optimum set that, when combined, correspond to the desired substrate deposition thickness uniformity over an area of specified size. FIG. **5** is an example of a specific set of weighted hypothetical deposition profiles that superimpose to achieve >99% thickness uniformity over a 4-inch diameter substrate. Other factors that influence this selection and weighting process include the planetary deposition mode and the desired deposition homogeneity. An example of the scan optimization program that simultaneously takes into consideration all of these factors would therefore be quite complicated. However, a program for re-optimizing the motion parameters for meeting specified thickness uniformity requirements after a source re-calibration is quite representative of the overall motion scenario optimization program, and is much easier to communicate. Therefore, the example of a re-optimization of motion scenario parameters shown in FIG. **20** is presented, where for simplicity it is assumed that the deposition area, planetary mode, and deposition homogeneity requirements were already addressed in the original optimization of motion scenario parameters for this particular deposition scenario. In this instance, the procedure is to read the old (prior to re-calibration) set of motion scenario parameters, as indicated by block **541**. The new hypothetical deposition profiles based on the re-calibrated source distribution are then read in at block **542**. Blocks **543**, **544** and **545** involve sequentially incrementing the old motion scenario parameters and then calculating the corresponding thickness uniformity to see if it meets the specified requirement. If not, the incrementing of motion scenario parameters will continue as long as they remain within a pre-specified range of the old deposition parameters (block **546**). If they are out of range, additional operator input is required, as indicated by block **547**. Otherwise, the procedure continues until the required thickness uniformity is achieved. When this occurs, the new motion scenario parmeters are stored (block **548**) for use in the computation of deposition parameters (block **56** of FIG. **13**).

Finally, an example of the computation of deposition parameters is shown in FIG. **21**. This flow diagram is largely self-explanatory, since no loops are involved. Blocks **561**, **562**, and **563** indicate the sequential steps involved in computing the power supply settings corresponding to the specified deposition rate. Blocks **564**, **565**, and **566** indicate the sequential steps involved in computing the absolute scan positions (as indicated on the planetary encoder), given the substrate positions on the planetary and the relative scan positions (as referenced to the center of the source) computed in block **54** (FIG. **13**). Blocks **567**, **568**, and **569** indicate the sequential steps involved in calculating the number of deposition cycles (i.e., the number of complete repetitions of deposition positions) required to achieve the specified final deposition thickness, given the stop time at each deposition position. In the nomenclature of this invention, the stop time at each position is the product of the corresponding position weight and a minimum time determined by considerations of deposition homogeneity.

From the foregoing, it can be seen that the present invention offers an unprecedented combination of versatility, efficiency, and high performance. In the current preferred embodiment, it is ideally suited for research and development as well as low-volume production applications. However, it is clear that other embodiments of this invention can be straightforwardly implemented to address a much broader range of applications, including those involving high production. More generally, it will be obvious to those skilled in the art that many modifications may be made within the scope of the present invention without departing from the spirit thereof, and the invention includes all such modifications.

What is claimed is:

1. A physical vapor deposition system comprising:

at least one substrate;

at least one source for processing a thin film on the surface of said substrate;

a source-operating means for operating said source at different sets of values of operating parameters during said thin film processing;

a motion-and-positioning means for moving said substrate into different positions relative to said source during said thin film processing;

a calibration means for measuring and predicting the hypothetical processing profiles of said thin film processing, where a said hypothetical processing profile is the amplitude and shape of the result of said thin film processing per unit processing time obtained at any one of said processing positions while using any one of said sets of values of source operating parameters;

a modeling means for predicting the final processing profile of said thin film on said substrate that results from any specified weighted superposition of said hypothetical processing profiles; and

a control means for said source-operating means and said motion-and-positioning means for implementing any desired source-operating scenario and motion-and-positioning scenario during said thin film processing in order to effect any said weighted superposition;

to this predict and achieve a desired range of said final processing profiles of said thin film on said substrate, where said range is limited only by the diversity in shapes of said hypothetical processing profiles.

2. A system as in claim **1** where said range of said final processing profiles of said thin film on said substrate includes a final processing profile that is extremely uniform over the surface of said substrate, irrespective of the size of said substrate relative to said source.

3. A system as in claim **2** where the shape of said substrate is selected from the group of regular shapes

consisting of: planar, cylindrical, spherical, polyhedron, and combinations thereof.

4. A system as in claim 1 where said substrate is stationary during said thin film processing.

5. A system as in claim 1 where said source is stationary during said thin film processing.

6. A system as in claim 5 where said motion-and-positioning means includes a flat-plate planetary system with orbital and spin degrees of freedom that comprises:

a base that is fixed with respect to a plurality of said sources, where said sources are positioned in a substantially planar and circular array opposing said base;

a turntable rotatably mounted on said base where said turntable is free to rotate about an axis through its center; and

a plurality of planar substrates rotatably mounted on the circumference of said turntable, such that said planar substrates are free to spin about axes through their centers and where said planar substrates sequentially oppose said sources as a consequence of their orbital motion when said turntable is rotated.

7. A system as in claim 6 where said control means includes means for intermittently orbiting said planar substrates to a plurality of said different orbital processing positions for predetermined periods of time, and source-operating means for effecting said thin film processing at each of said orbital processing positions at predetermined processing rates.

8. A system as in claim 7 where said control means includes means for continuously spinning said planar substrates at each of said orbital processing positions, where said spinning is sufficiently fast that essentially circularly-symmetric spin-averaged processing profiles are obtained at each of said orbital processing positions during said predetermined periods of processing time.

9. A system as in claim 8 where said modeling means includes a computer means for modeling any time-weighted superposition of said spin-averaged processing profiles obtained at each of said orbital processing positions, where said computer means are used to determine a combination of said orbital processing positions and processing times that correspond to any specified spin-averaged said final processing profile.

10. A system as in claim 9 where said calibration means includes means for measuring a source distribution that is cylindrically symmetric about an axis perpendicular to said planar substrates, where said source distribution is said final processing profile obtained on a said planar substrate that is centered with respect to said source.

11. A system as in claim 10 where said calibration means includes a computer model of said motion-and-positioning means that is used to predict the remainder of said spin-averaged processing profiles in terms of the source distribution of any said cylindrically-symmetric source.

12. A system as in claim 6 where said motion-and-positioning means includes a resistance-element heater mounted on a flat-plate shutter that is rotatably mounted with respect to and positioned between said sources and said substrates, where said shutter has an open portion therein that is positioned so that sequential alignment of said open portion with said sources is obtained when said shutter is rotated.

13. A system as in claim 12 where said resistance-element heater is positioned on said shutter so that sequential front-side heating of said substrate occurs when said shutter is rotated.

14. A system as in claim 5 that includes means for heat sinking said substrate without restricting the motion of said substrate relative to said source.

15. A system as in claim 14 where said heat-sinking means includes a phase-change material.

16. A system as in claim 1 where said thin film processing is selected from the group consisting of: depositing, etching, and heating.

17. A system as in claim 16 where said source is used to deposit said thin film on said substrate, where said deposition source is selected from the group consisting of: diode, triode, and magnetron DC/RF sputtering sources, thermal and electron-beam evaporation sources, secondary-ion-beam deposition sources, and molecular-beam-epitaxy sources.

18. A system as in claim 16 where said source is used to etch said thin film on said substrate, where said etching source is selected from the group consisting of: ion-beam etching and milling sources.

19. A system as in claim 16 wherein said source is used to heat said thin film on said substrate, where said heating source is selected from the group consisting of: resistive-element radiative heaters and quartz-tube radiative heaters.

20. A system as in claim 19 where said heating source is a resistive-element heater whose resistance changes with temperature.

21. A system as in claim 20 where said resistance change with temperature is sufficiently large that only one high-vacuum insulated electrical feedthrough is required to simultaneously power, monitor, and regulate the performance of said resistive-element heater.

22. A system as in claim 21 where said positioning means includes means for moving said resistance-element heater relative to a stationary said substrate.

23. A system as in claim 22 wherein said means for moving said resistance-element heater relative to a stationary said substrate includes just one sliding electrical contact bewteen the moving and non-moving portions of said positioning means.

24. A system as in claim 1 where the type of motion used by said motion-and-positioning means in moving between said different processing positions are selected from the group consisting of: constant speed, straight-line, circular, oscillating, orbiting, spinning, continuous, intermittant, and combinations thereof.

25. A system as in claim 1 where said control means for controlling said source-operating means and said motion-and-positioning means includes a computer.

26. A system as in claim 1 where said control means for said source-operating means includes means for continuously varying said values of source-operating parameters so that a continuous range of amplitudes of said fundamental processing profiles are available at each of said different processing positions.

27. A system as in claim 1 where said control means for said motion-and-positioning means includes means for repetitively moving said substrate to said different processing positions in order to enhance the homogeneity of said thin film processing.

28. A system as in claim 1 where said modeling means includes a computer means for modeling any said time-weighted superposition of said hypothetical processing profiles, where said computer means are used to determine a said source-operating scenario and motion-and-

positioning scenario that corresponds to any specified said final processing profile.

29. A system as in claim 1 where said calibration means includes measurement means for measuring at least one said fundamental processing profile.

30. A system as in claim 29 where said measurement means includes a computer for data acquisition and analysis means.

31. A system as in claim 29 where said measurement means includes in-situ process monitoring means and means for moving said in-situ process monitoring means relative to said source.

32. A system as in claim 31 where said means for moving said in-situ process monitoring means relative to said source is said motion-and-positioning means.

33. A system as in claim 31 that includes sliding electrical contacts between the moving and non-moving portions of said measurement means.

34. A system as in claim 31 where said in-situ process monitoring means includes a quartz crystal monitor.

35. A system as in claim 34 that includes means for heat sinking said quartz crystal monitor.

36. A system as in claim 34 where said quartz crystal monitor can be used as either a deposition or an etch monitor.

37. A system as in claim 31 where said in-situ process monitoring means includes a thermal monitor.

38. A system as in claim 37 where said thermal monitor includes a thermocouple.

39. A system as in claim 37 where said thermal monitor includes a resistance thermometer.

40. A system as in claim 31 where said in-situ process monitoring means includes an ion-beam current monitor.

41. A system as in claim 40 where said ion-beam current monitor includes a Faraday cup.

42. A system for sequential in-situ heating of stationary substrates in a vacuum system comprising:

a resistive-element heater, where said resistive element comprises a material with a sufficiently large temperature coefficient of resistance that only one high-vacuum insulated electrical feedthrough is required to power, monitor, and control the performance of said resistive-element heater; and

a motion-and-positioning means for moving said resistive-element heater to different heating positions with respect to said stationary substrates.

43. A system as in claim 42 where said means for moving said resistive-element heater with respect to said stationary substrates includes just one sliding electrical contact be- tween the moving and non-moving portions of said motion-and- positioning means.

44. A system as in claim 42 where said resistance-element material is platinum.

45. A system as in claim 42 where said resistance element is supported by an electrical insulator.

46. A system as in claim 42 where said resistance-element heater is a thick-film platinum filament patterned onto an alumina substrate.

47. A system for determining source distributions of thin film processing sources in physical vapor deposition systems that comprises:

an in-situ quartz crystal processing monitor sensitive to the amount of said thin film processing thereon;

a motion-and-positioning means for at least intermittently moving said processing monitor on a hypothetical surface with respect to said source;

a data acquisition and analysis means responsive to said processing monitor and said motion-and-positioning means for determining said source distribution, where said source distribution is the result of said thin film processing by said source on a substrate surface coincident with said hypothetical surface.

* * * * *

US006203620B1

(12) United States Patent
Moslehi

(10) Patent No.: **US 6,203,620 B1**
(45) Date of Patent: **Mar. 20, 2001**

(54) **HERMETICALLY-SEALED INDUCTIVELY-COUPLED PLASMA SOURCE STRUCTURE AND METHOD OF USE**

(76) Inventor: **Mehrdad M. Moslehi**, 956 Stanley Ave., Los Altos, CA (US) 94024

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/539,336**

(22) Filed: **Mar. 30, 2000**

Related U.S. Application Data

(62) Division of application No. 08/677,849, filed on Jul. 10, 1996.

(51) **Int. Cl.**[7] **C23C 16/507**

(52) **U.S. Cl.** .... **118/723**; 118/723 R; 216/67; 216/71

(58) **Field of Search** .... 156/345 C; 118/723 I, 118/723 IR; 204/298.34

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Primary Examiner—Gregory Mills
Assistant Examiner—Rudy Zervigon
(74) *Attorney, Agent, or Firm*—Gray Cary Ware & Friedenrich LLP.

(57) **ABSTRACT**

A multi-zone high-density inductively-coupled plasma source includes a first individually controlled RF antenna segment for producing a plasma from a process gas. A second individually controlled coil segment is included in the ICP source for producing a plasma from a process gas. In various embodiments, more than two sets of individually controlled coil segments may be used. In one embodiment, a separate power supply may be used for each coil segment individually.

Another aspect of this invention is a hermetically-sealed inductively-coupled plasma source structure and method of fabrication which eliminates the possibility of process contamination, improves the source hardware reliability and functionality, and improves the vacuum integrity and ultimate base pressure of the plasma system.

22 Claims, 14 Drawing Sheets

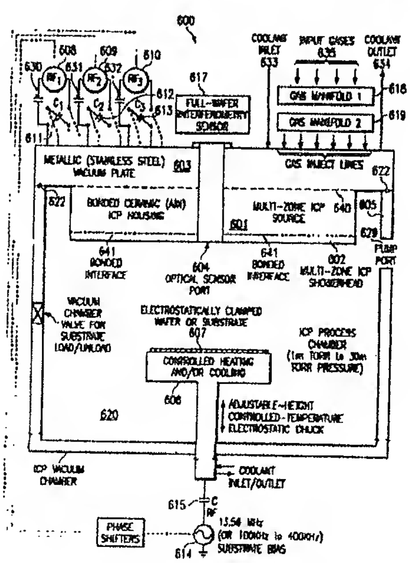
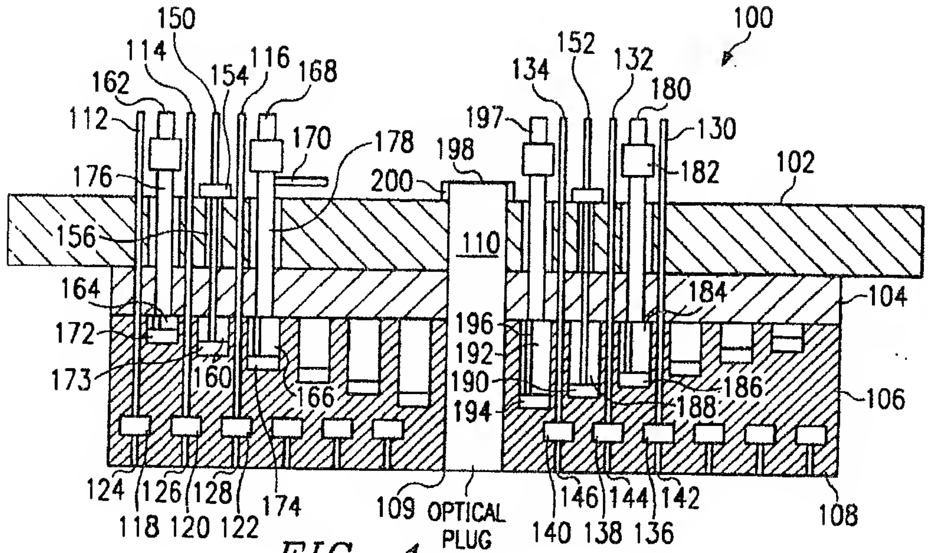


Exhibit D



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OPTICAL PLUG
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FIG. 1

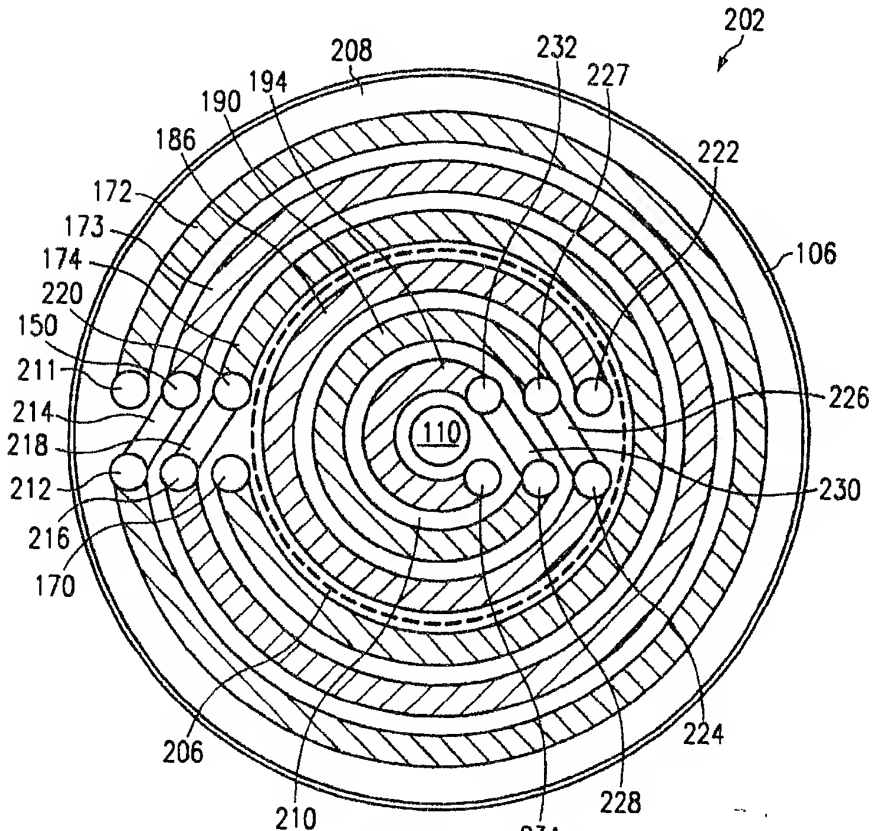

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FIG. 2

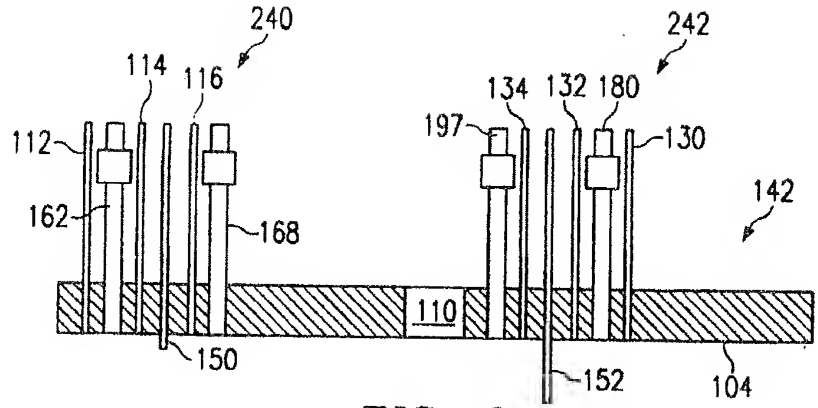
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FIG. 3

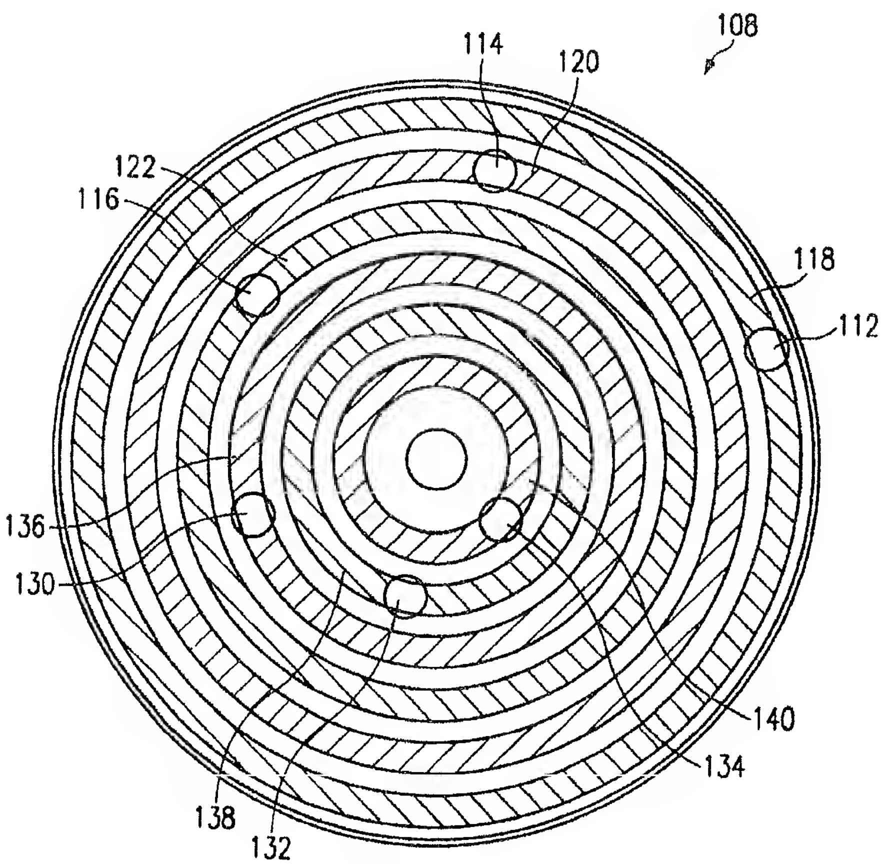
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FIG. 4

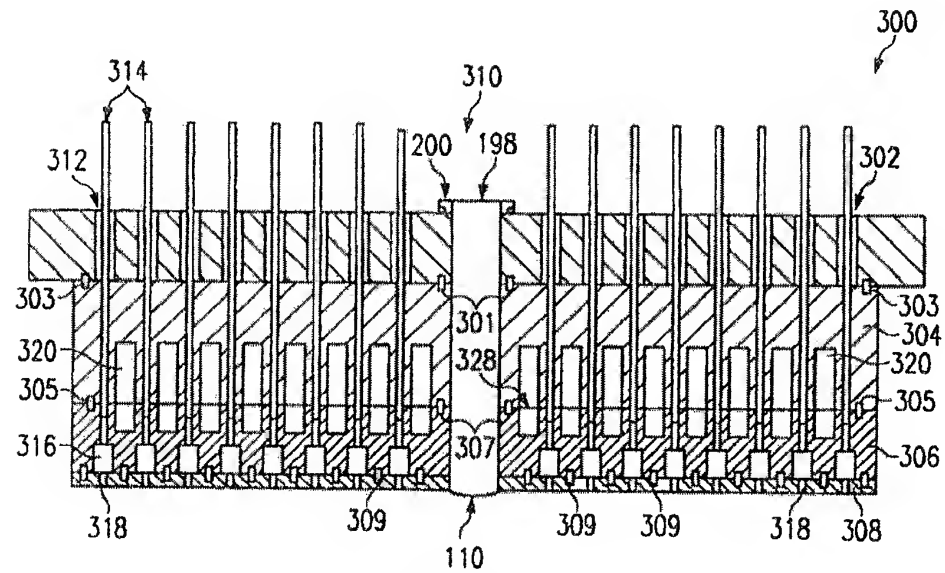
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FIG. 5

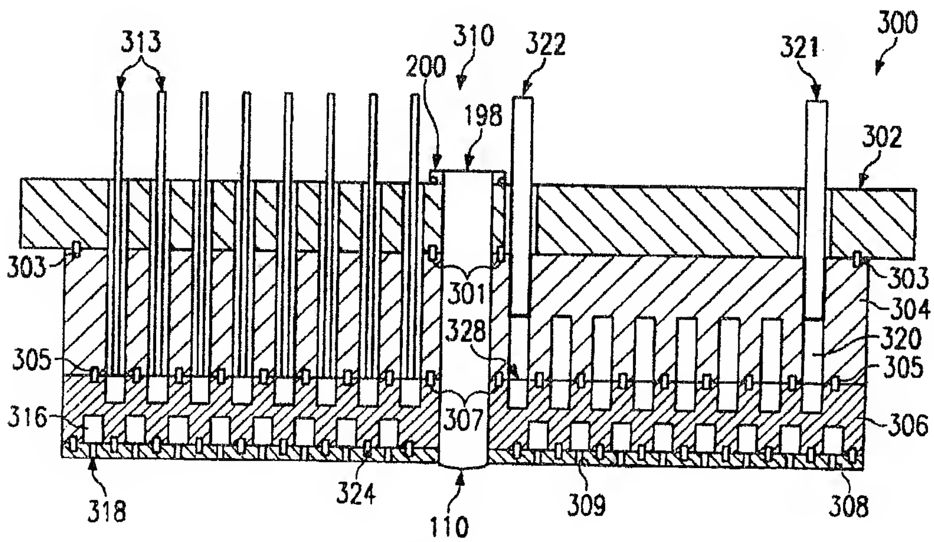
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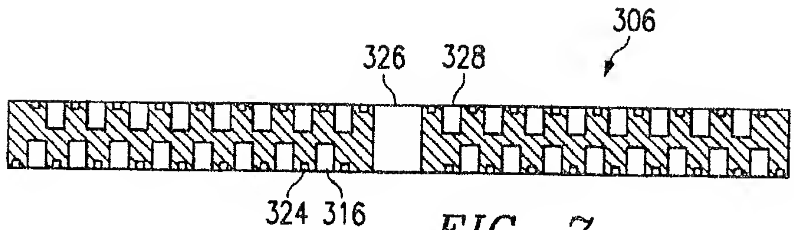
FIG. 6



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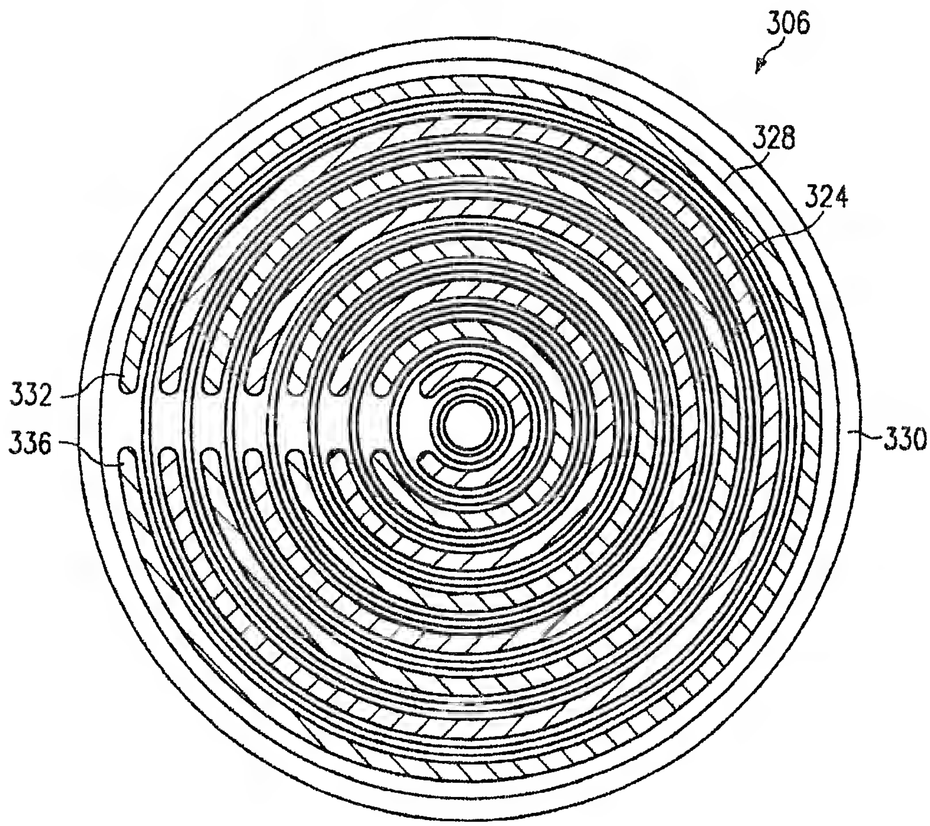
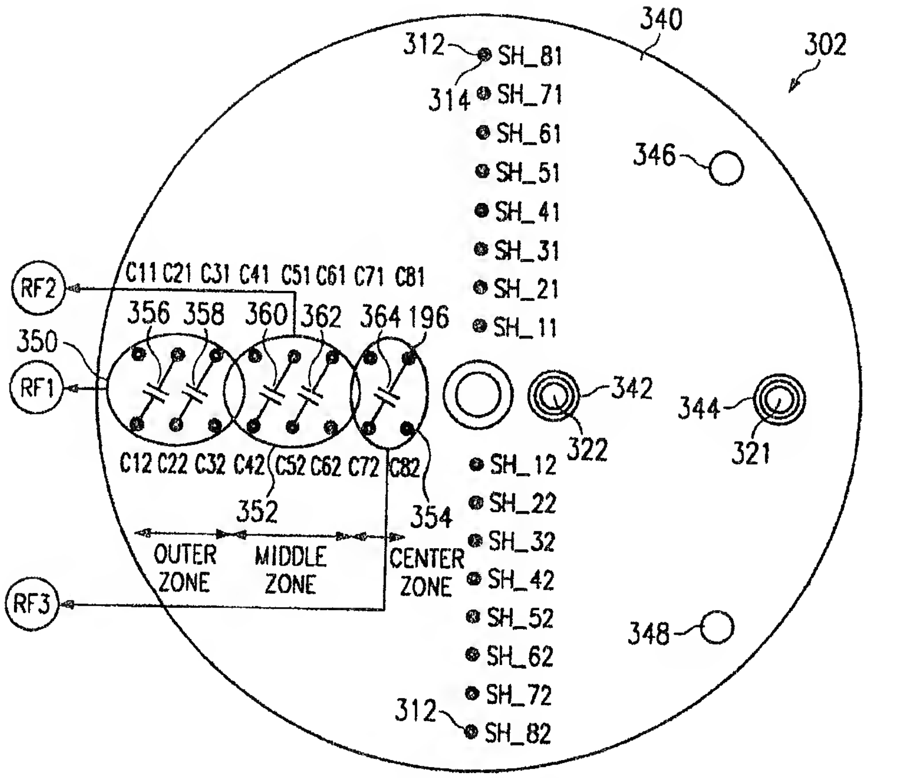


FIG. 8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350
RF1
342
344
322
321
C12 C22 C32 C42 C52 C62 C72 C82
SH_12
SH_22
SH_32
SH_42
SH_52
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SH_72
SH_82
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OUTER ZONE
MIDDLE ZONE
CENTER ZONE
RF3
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312

FIG. 9

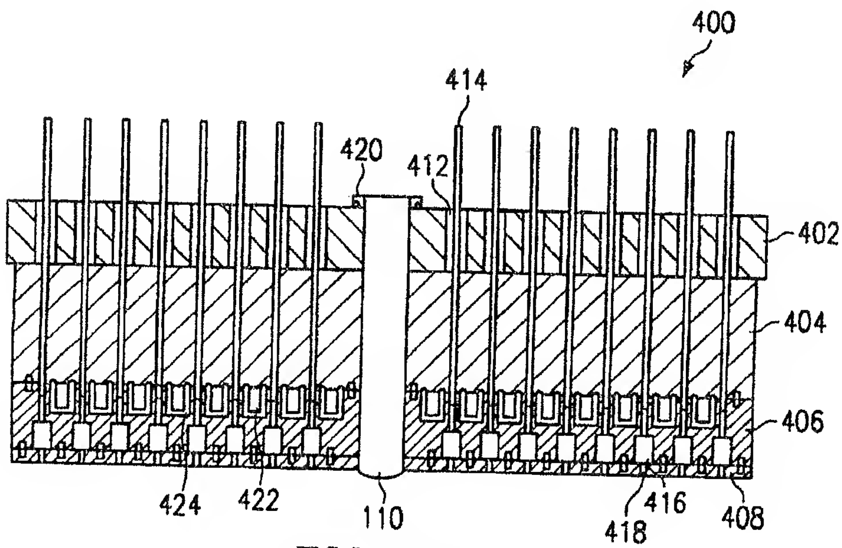
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FIG. 12

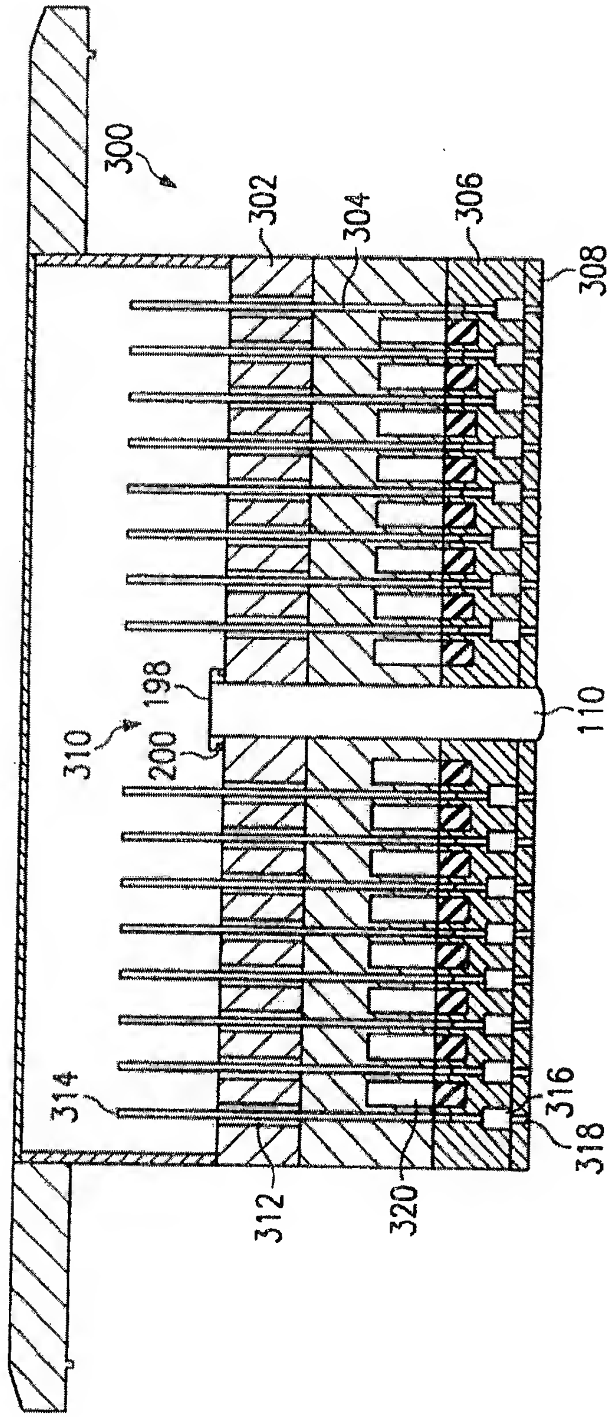

FIG. 10

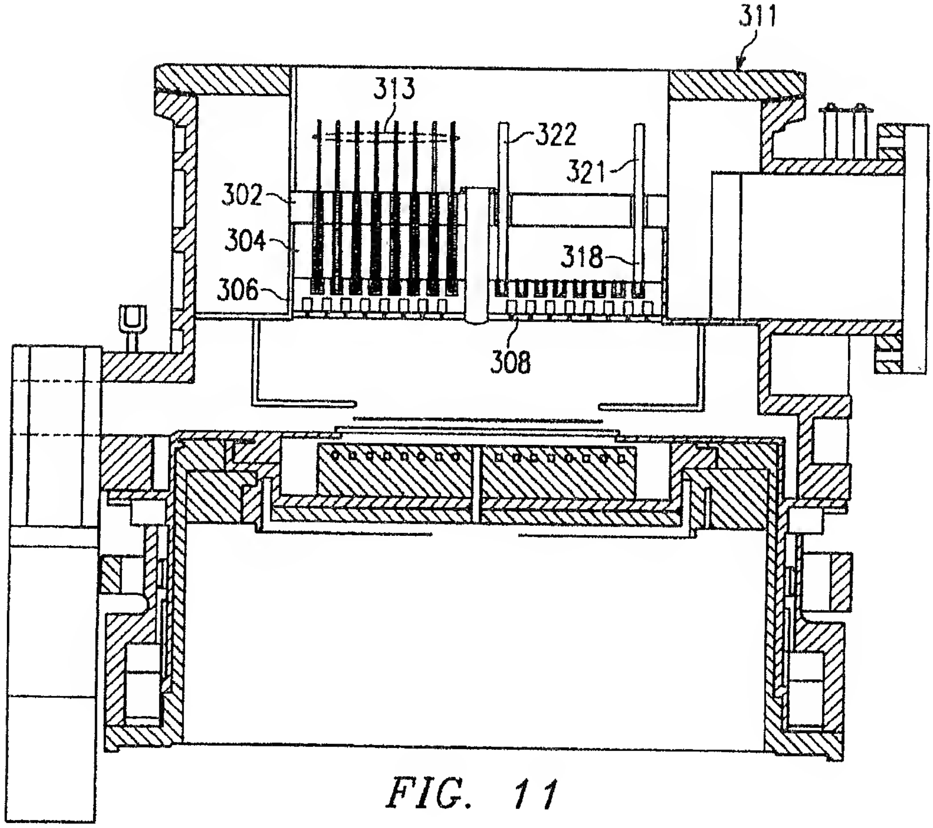
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FIG. 11

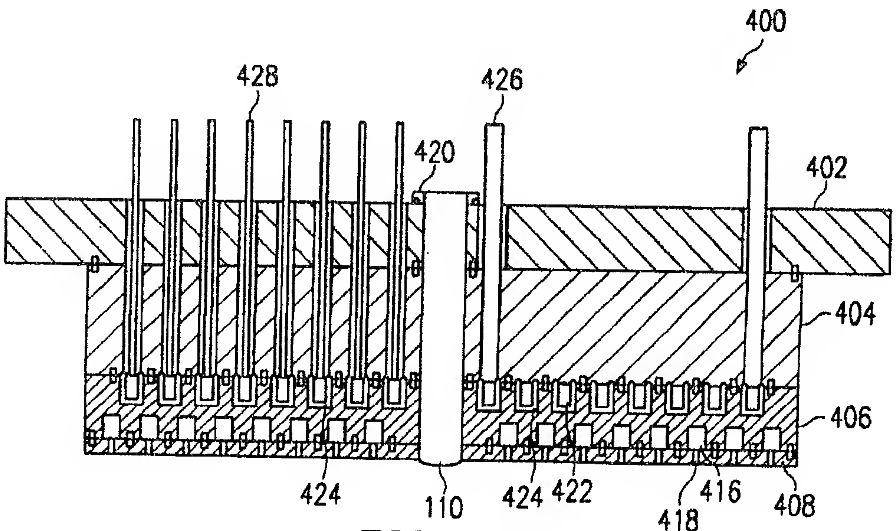
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FIG. 13

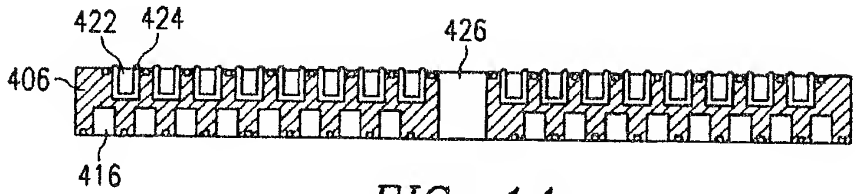
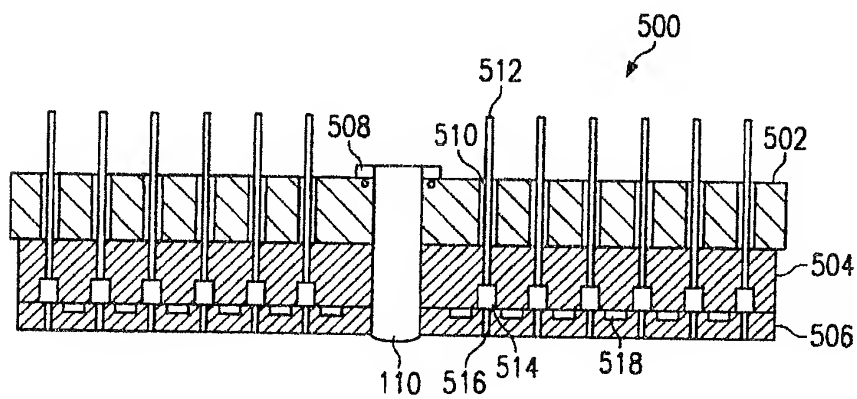


FIG. 14



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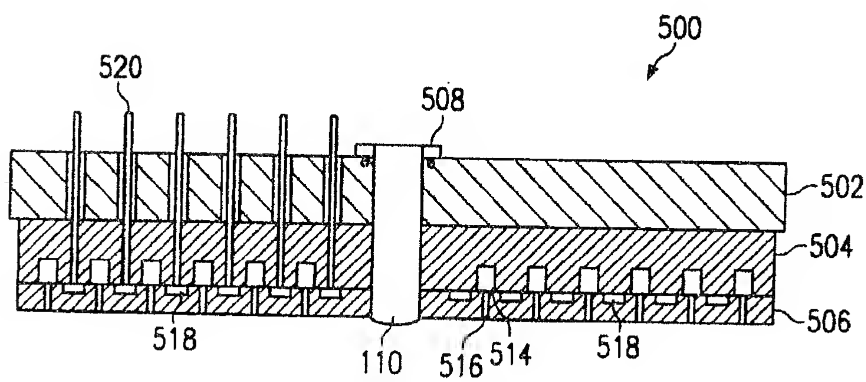
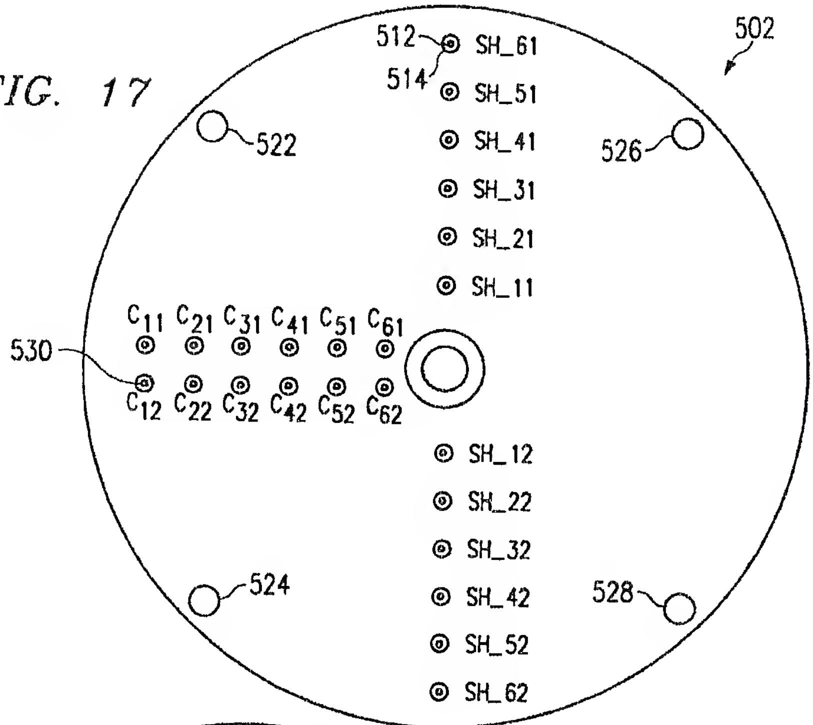


FIG. 16

FIG. 17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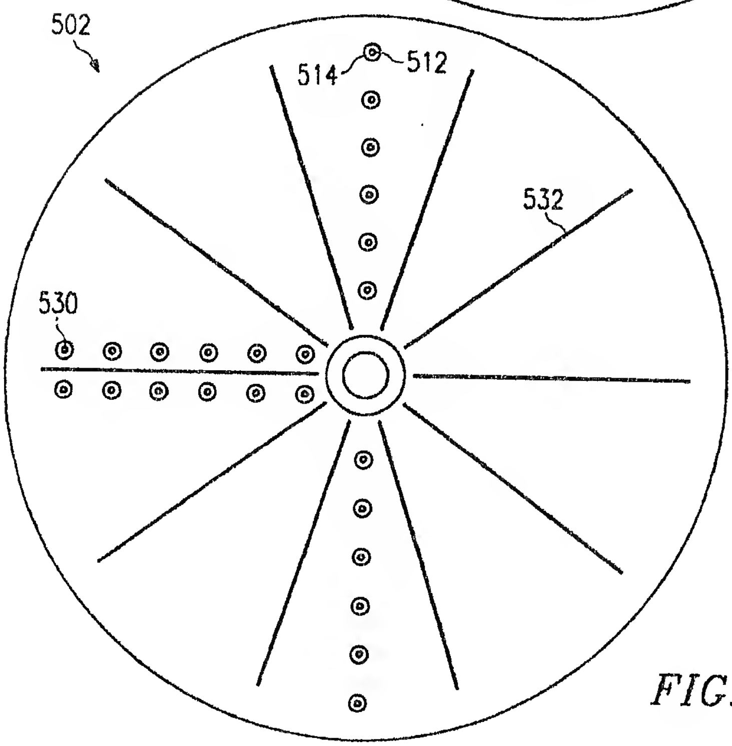
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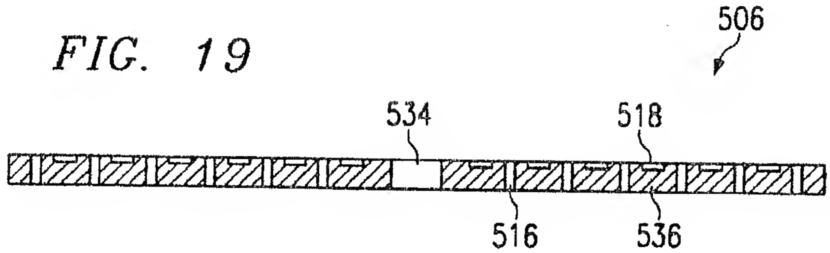
FIG. 18

FIG. 19



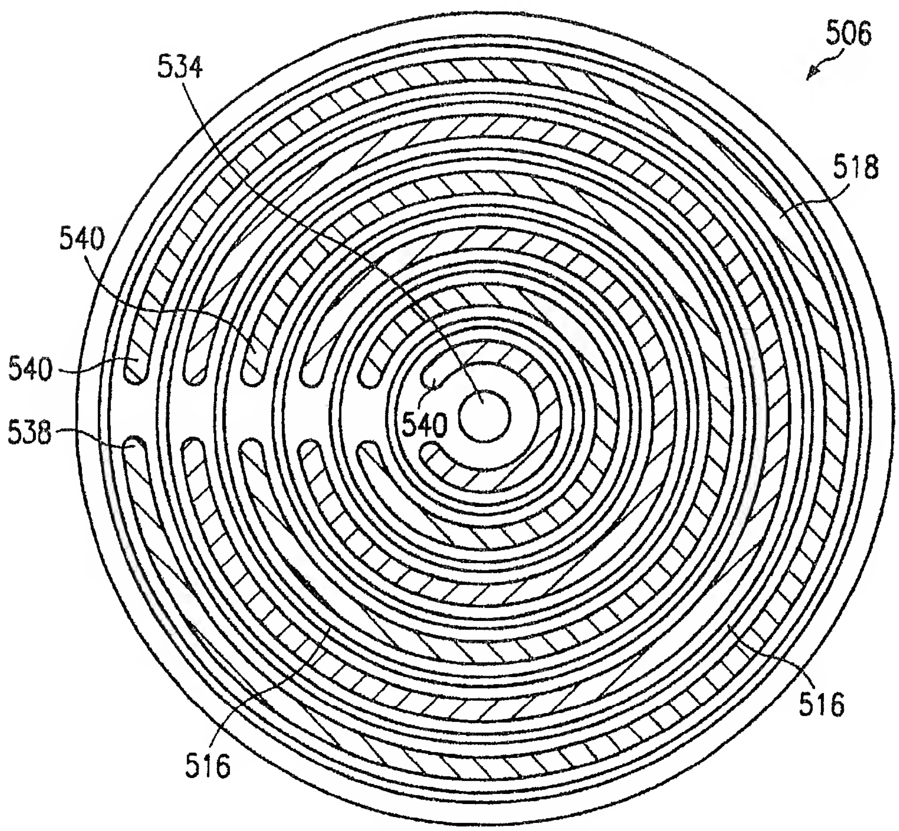


FIG. 20

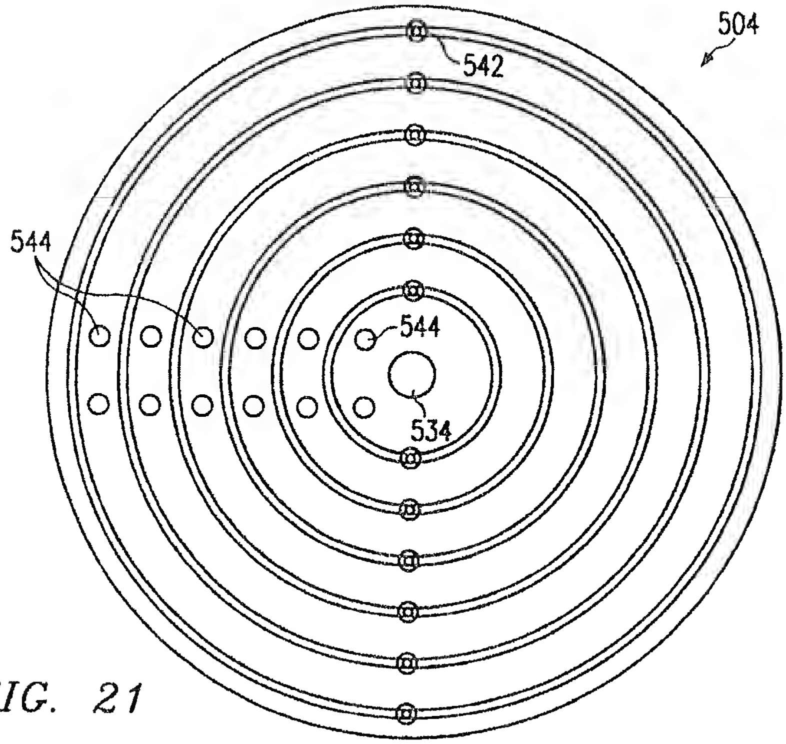

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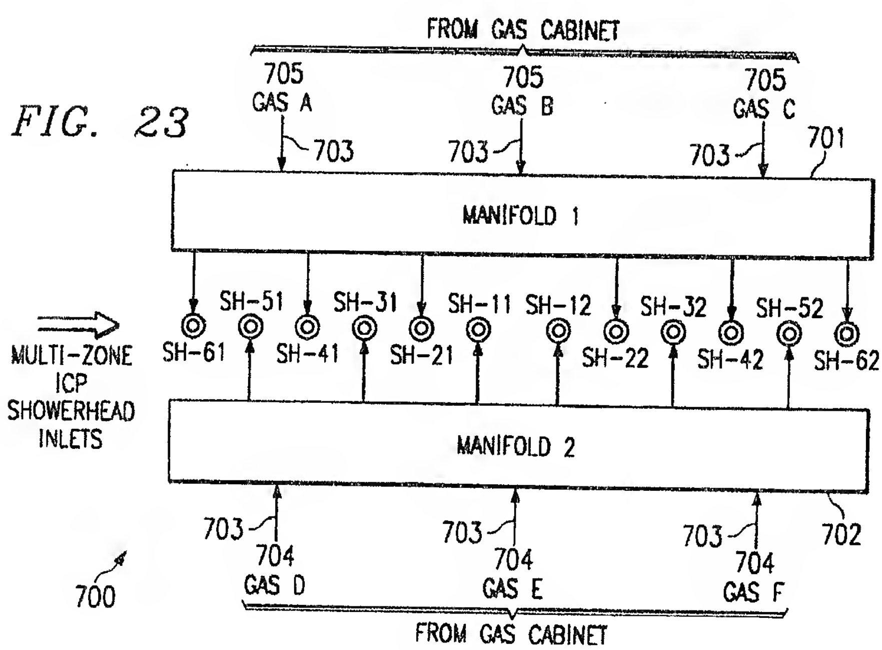
FIG. 21

FIG. 23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GAS A
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SH-32
SH-52
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SH-41
SH-21
SH-22
SH-42
SH-62
MULTI-ZONE
ICP
SHOWERHEAD
INLETS
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GAS E
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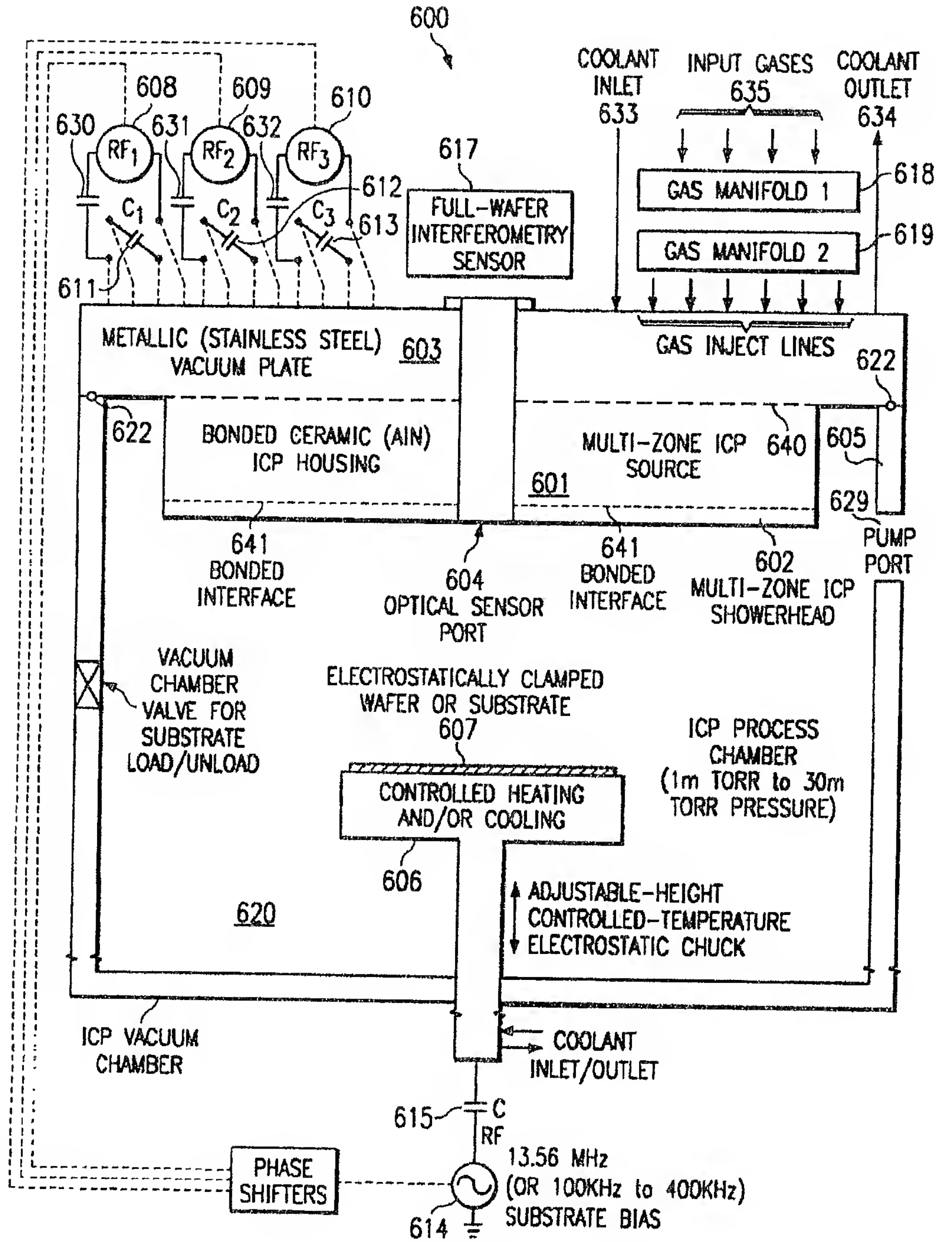
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RF2
RF3
C1
C2
C3
612
613
611
617
FULL-WAFER INTERFEROMETRY SENSOR
GAS MANIFOLD 1
618
GAS MANIFOLD 2
619
METALLIC (STAINLESS STEEL) VACUUM PLATE 603
GAS INJECT LINES
622
622
BONDED CERAMIC (AIN) ICP HOUSING
MULTI-ZONE ICP SOURCE
601
640
605
629
PUMP PORT
641 BONDED INTERFACE
604 OPTICAL SENSOR PORT
641 BONDED INTERFACE
602 MULTI-ZONE ICP SHOWERHEAD
VACUUM CHAMBER VALVE FOR SUBSTRATE LOAD/UNLOAD
ELECTROSTATICALLY CLAMPED WAFER OR SUBSTRATE 607
ICP PROCESS CHAMBER (1m TORR to 30m TORR PRESSURE)
CONTROLLED HEATING AND/OR COOLING
606
620
ADJUSTABLE-HEIGHT CONTROLLED-TEMPERATURE ELECTROSTATIC CHUCK
ICP VACUUM CHAMBER
COOLANT INLET/OUTLET
615
C
RF
13.56 MHz (OR 100KHz to 400KHz) SUBSTRATE BIAS
PHASE SHIFTERS
614

FIG. 22

FIG. 24A

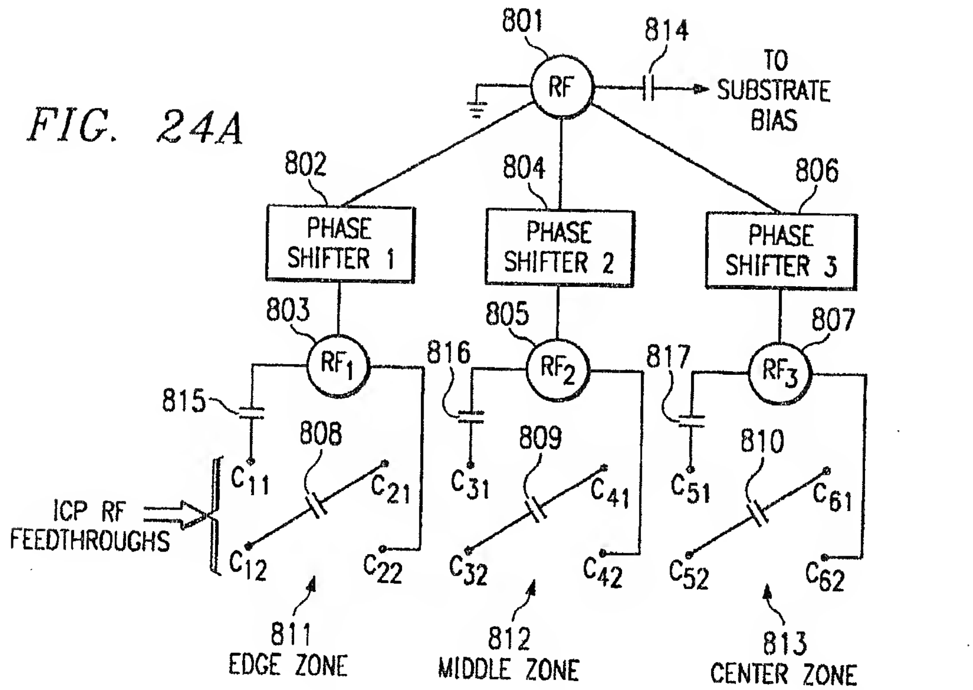


FIG. 24B

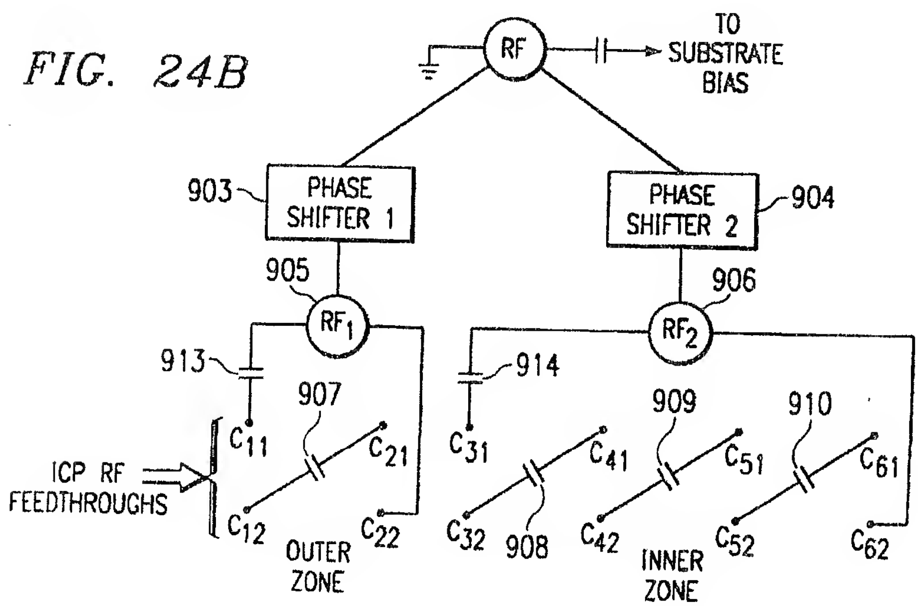


FIG. 25A

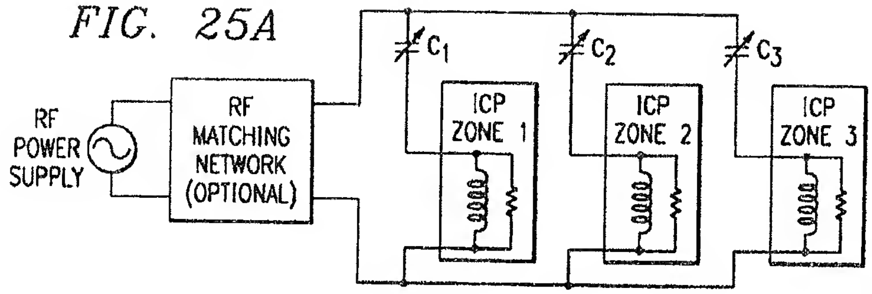


FIG. 25B

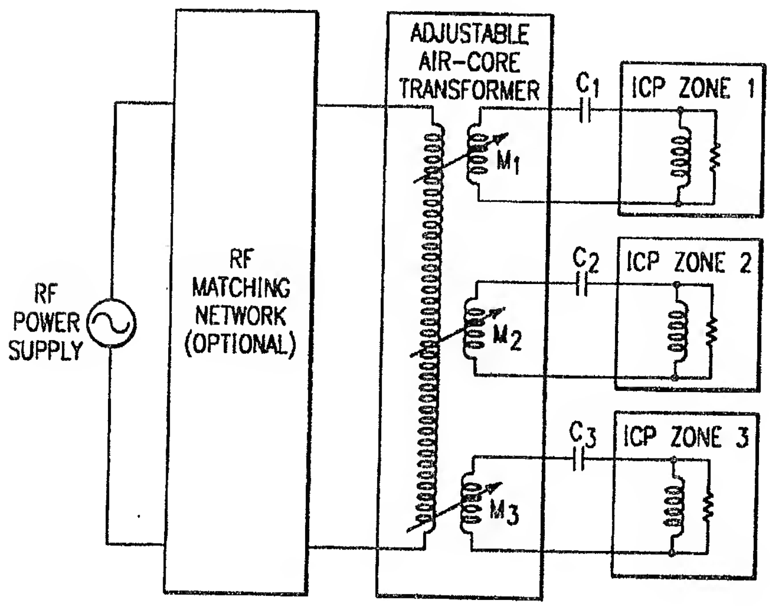
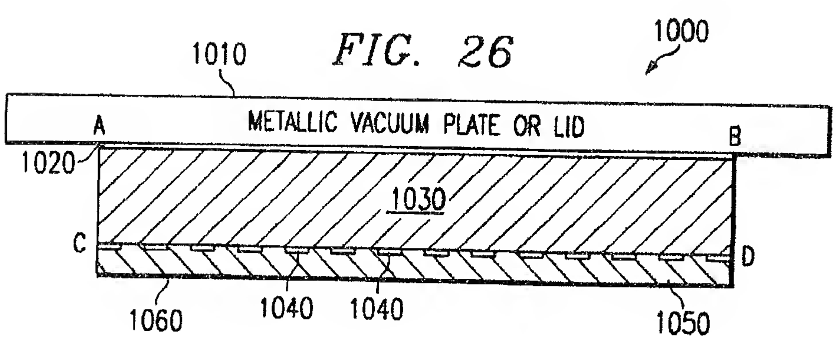


FIG. 26



HERMETICALLY-SEALED INDUCTIVELY-COUPLED PLASMA SOURCE STRUCTURE AND METHOD OF USE

This application is a divisional of Ser. No. 08/677,849 filed Jul. 10, 1996.

TECHNICAL FIELD OF THE INVENTION

This invention relates generally to plasma processing methods and systems, and more particularly to an apparatus and method for hermetically-sealed inductively-coupled plasma generation source structure for plasma-assisted fabrication processes used for manufacturing of semiconductor, data storage, flat-panel display, photovoltaic, and multi-chip module devices, and method for manufacture of same.

BACKGROUND OF THE INVENTION

Plasma processes are used for numerous fabrication steps in various device manufacturing applications such as semiconductor integrated circuit, data storage device (heads and media), and flat-panel display manufacturing. Typically, plasma processes (also known as plasma-enhanced or plasma-assisted processes) are used for physical-vapor deposition (PVD), plasma-enhanced chemical-vapor deposition (PECVD), dry etching, wafer cleaning (or surface preparation), in-situ chamber cleaning, and plasma-immersion ion implantation (also known as plasma doping) applications. Conventional or prior art methods of plasma generation employ one or a combination of several techniques. Various plasma generation techniques include parallel-plate capacitive discharge, microwave discharge (including electron cyclotron resonance or ECR plasma), hollow cathode discharge, and inductively-coupled plasma (ICP) sources.

The high-density inductively-coupled plasma or ICP sources have recently received a significant amount of attention due to their superior process performance, throughput rate, and control capabilities. ICP sources can provide high-density (n_p values ranging from 1×10^{11} cm^{-3} to over 5×10^{12} cm^{-3}) plasmas using fairly simple inductive radio frequency (RF) excitation. Advanced ICP source designs are capable of producing fairly high plasma densities (corresponding to the plasma electron density or n_p) even larger than 1×10^{13} cm^{-3}. The RF source frequency is typically in the range of 1 to 30 MHZ (with a preference for 13.56 MHZ). RF frequencies in the low end of this range result in reduced induced RF voltages across the ICP antenna. This reduces the risk of capacitive coupling as well as sputtering of the inner process chamber and ICP source walls near the ICP antenna. Lower ICP source frequencies, however, result in reduced plasma densities and larger RF matching network components. On the other hand, higher RF frequencies can provide superior plasma densities and can be effectively coupled to the plasma load using more compact RF matching network components. However, precautions must be taken to ensure that no chamber wall sputtering occurs due to the relatively high induced RF voltages that arise across the antenna. Higher induced RF voltages across the ICP source antenna can increase the risk of capacitive coupling and raising the plasma potential.

One advantage of ICP over conventional parallel plate plasma is its ability to control the plasma density and ion energy (for the ion flux arriving at the substrate in process) independent of each other. The plasma density is primarily controlled by the applied RF current or power delivered to the ICP source antenna, whereas the mean ion energy control is performed by an applied RF bias to the substrate or wafer. The substrate may be a semiconductor wafer (e.g., silicon), a data storage substrate (AlSiMag or AlTiC), a photovoltaic substrate (e.g., polysilicon or silicon), or a flat-panel display substrate (e.g., glass).

Various types of ICP source designs have been proposed in prior art. These include spiral coil antenna designs, helicon wall source designs, and cylindrical coil antenna source designs. However, all the prior art ICP designs share a common constraint or limitation which makes them unable to control or adjust the plasma uniformity profile in real time. The prior art ICP sources are primarily based on single-zone designs and employ single-coil antenna structures with a single RF plasma excitation source. The basic prior art designs mostly employ either a cylindrical or cone-shaped coil around a quartz chamber (such as a quartz bell jar) to generate a large-volume plasma or a planar spiral coil above a dielectric plate (outside the vacuum chamber) to generate a so-called planar plasma. The spiral coil ICP design often uses a flat spiral coil, but provides the options to contour the surface topography of the ICP antenna dielectric housing and/or the antenna coil itself for improved plasma uniformity.

The spiral coil design possesses certain technical advantages, but also has serious limitations. The spiral coil design allows placement of the antenna above a vacuum dielectric plate on the atmospheric side or within the vacuum chamber using an epoxy encapsulation. One can provide a capability to reduce the induced RF voltage across the spiral coil by placing a few capacitors in series with the spiral coil loops. This is not a trivial implementation task since the antenna coil is usually made of water-cooled aluminum or copper tubing. Insertion of the series capacitors may require breaking the tubing water flow by insertion of an in-line metal-to-ceramic insert. Unfortunately, this results in added structural complexity and increased equipment cost. The ICP sources with cylindrical coils around the electrically insulating plasma source or process chamber require an electrically insulating process chamber or plasma source wall material such as quartz tube or aluminum oxide tube used in some source designs such as the helicon plasma sources. These bulk ICP sources can suffer from plasma non-uniformity problems and usually require a multipolar magnetic bucket inserted between the plasma source chamber and the process environment to generate an expanded uniform plasma. This, however, results in reduced processing throughput due to reduced plasma density and ion flux density at the substrate. Moreover, these sources may generate contaminants and particulates due to sputtering of the plasma source chamber wall material near the excitation RF antenna.

The ICP coil is usually driven by a 13.56 MHZ RF source. The RF current also induces an RF voltage across the antenna coil. In order to eliminate any electric field induced arcing or chamber sputtering, the amount of induced RF voltage must be minimized. This condition places a limit on the maximum allowable excitation coil inductance or the number of coil turns. Moreover, for a given coil design (e.g., a given number of turns or inductance) there is an upper limit on the maximum allowable RF source frequency. In addition, for a given conventional ICP source design and a specified excitation RF frequency (e.g., 13.56 MHZ), there is a limit on the maximum allowable RF power delivered to the ICP antenna in order to ensure minimal chamber or plasma source wall sputtering and reduced process contamination. The prior art designs for ICP coils, therefore, mostly suffer from plasma process nonuniformity problems, are not

easily scalable for larger wafer processing, and have a relatively narrow useful process window (in terms of RF power, pressure, etc.). The conventional ICP designs do not provide any direct method of real-time plasma uniformity control without compromising the significant process state or substrate state parameters.

Advanced plasma fabrication processes require excellent plasma density and ion flux uniformity control over the entire wafer surface. Plasma uniformity requirements in high-density plasma sources are dictated by both process uniformity requirements and device damage considerations. Typically, the plasma nonuniformity must be less than 5% (3-sigma value) to ensure damage-free uniform processing. Many conventional ICP source designs fail to meet these stringent process uniformity requirements for various plasma processing applications.

SUMMARY OF THE INVENTION

In accordance with the present invention, a method and system for creating an inductively-coupled plasma (ICP) environment for various device fabrication applications is provided that substantially eliminates or reduces disadvantages and problems associated with previously developed ICP processing methods and systems. The ICP processing method and system of this invention is applicable to manufacturing of semiconductor, data storage, flat-panel display, and photovoltaic devices.

According to one aspect of the invention, there is provided a multi-zone high-density inductively-coupled plasma source structure and method of use that includes a first individually controlled inductive coil for producing a first plasma zone from a process gas. A second individually controlled coil is included in the ICP source for producing a second plasma zone from a process gas. In various embodiments, more than two individually controlled inductive coils may be used. In one embodiment, a separate RF power supply may be used for each ICP coil zone. Each ICP coil zone may be made of either a single coil segment or a set of coil segments interconnected using at least one series capacitor.

Another aspect of the present invention is a hermetically-sealed ICP source structure and fabrication method that are applicable to both the multi-zone ICP structure of the present invention as well as the conventional single-zone ICP structures. By forming the ICP antenna and its encapsulation housing as a single hermetically-sealed structure, the present invention eliminates the need for various seals and encapsulations for the ICP excitation antenna and associated housing. Moreover, the monolithic ICP structure and fabrication method of this invention provide better ICP structural integrity, plasma source reliability, and vacuum integrity in the process environment.

In the multi-zone ICP source of this invention, the RF current magnitude (and phase) can be adjusted in each zone independently. The multi-zone ICP source design of this invention offers several advantages over the conventional single-zone designs. These include (1) significantly improved plasma uniformity (plasma density and ion current density) as a result of the features provided for real-time uniformity control; (2) a much wider process window due to the multi-zone plasma adjustment capability; (3) increased plasma density and ion flux density; (4) a design that is scalable for large substrate processing (such as for 300-mm or larger silicon wafers and flat-panel display substrates); (5) a lower number of coil turns per zone to ensure that no electric field induced arcing or sputtering of the chamber and plasma source wall material occurs; (6) a capability for real-time or run-by-run control of plasma process parameters including uniformity using suitable in-situ monitoring sensors; (7) improved manufacturing equipment cleanliness for enhanced device manufacturing yield; (8) increased plasma process throughput; and (9) improved plasma equipment reliability and process repeatability/performance due to improved ICP source integrity.

The multi-zone ICP source design is applicable to manufacturing of semiconductor devices, data storage devices, photovoltaic devices, and flat-panel displays. Selection of the number of ICP zones depends on several parameters and considerations including ICP source diameter, substrate size, source design type, maximum total RF power, and plasma process throughput requirements. For most of the practical applications semiconductor processing, the number of the ICP source zones may be two to four, however, greater number of zones may be desirable for different applications such as those for very large-area substrate processing. For instance, a two-zone ICP source (antenna) design may be used to adjust the relative edge-to-center plasma process uniformity in a plasma equipment used for processing of 150-mm or 200-mm semiconductor wafers. An ICP source design with two to five excitation zones may be used for processing of 200-mm and 300-mm silicon wafers.

A technical advantage of the present invention therefore, is that it provides multi-zone high-density plasma source structure using at least two individually controlled coil segments for uniform plasma processing. The multi-zone ICP source structure of this invention may be constructed either using the more conventional ICP source fabrication and assembly methods (i.e., at least two cooled or temperature-controlled coils placed either outside the process chamber adjacent to a dielectric vacuum plate or encapsulated in an electrically insulating housing inside the ICP vacuum process chamber), or using a hermetically-sealed antenna structure placed within the vacuum environment.

Another technical advantage of the present invention is that is provides a hermetically-sealed ICP source fabrication structure and method that are applicable to both the conventional single-zone ICP structures as well as the multi-zone ICP source structure of this invention. This novel method and structure eliminates the need for elastomer O-ring seals and separate ICP antenna epoxy encapsulation by providing a high-integrity ICP source structure compatible with the ultrahigh vacuum (UHV) base pressure requirement of 5×10^{-9} Torr or less.

Yet a further technical advantage of the present embodiment is an in-situ sensor view port design which can be used for implementation of some useful plasma state and wafer state sensors such as full-wafer interferometry sensor and a spatially resolved optical emission sensor. The full-wafer-view optical port uses a hermetically sealed optical (e.g., sapphire or quartz) window or plug located at the center of the ICP source. This port enables real-time (or run-by-run) plasma process uniformity control using the multi-zone ICP source design of this invention in conjunction with a process uniformity monitoring sensor (such as a full-wafer interferometry sensor).

The hermetically-sealed aspect of the present invention provides an important technical advantage by eliminating elastomer seals by replacing them with hermetic seals that provide improved process cleanliness, enhanced vacuum integrity, and improved source lifetime.

The hermetically-sealed aspect of the present invention provides another technical advantage by providing low

thermal resistance heat transfer junctions to allow cooling of the ICP housing by a portion of the present invention.

The hermetically-sealed aspect of the present invention provides another technical advantage by greatly reducing or eliminating the possibility of outgassing.

The hermetically-sealed aspect of the present invention provides yet another technical advantage by increasing ICP source reliability, extending the ICP source lifetime and enhancing process cleanliness resulting in a reduces cost of ownership while enabling high-performance plasma processing.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the present invention and the advantages thereof, reference is now made to the following description which is to be taken in conjunction with the accompanying drawings in which like reference numerals indicate like features and wherein:

FIG. 1 shows a cross-sectional view of a first embodiment of the multi-zone ICP source of present invention configured as a two-zone ICP source;

FIG. 2 provides a view of the two-zone inductively-coupled plasma antenna portion embedded in the middle ceramic ICP or dielectric plate for the FIG. 1 embodiment (first embodiment);

FIG. 3 shows a cross-sectional view of the top ceramic or dielectric plate of the FIG. 1 embodiment (first embodiment);

FIG. 4 illustrates the bottom view of the middle dielectric plate indicating the gas dispersion cavities and their associated gas injection inlets for the multi-zone ICP embodiment of FIG. 1 (the first embodiment);

FIG. 5 depicts a first cross-sectional view of an alternative or second embodiment of multi-zone ICP structure of the present invention;

FIG. 6 shows a second cross-sectional view of the FIG. 5 embodiment (second embodiment) of the invention;

FIG. 7 provides a cross-sectional view of the middle dielectric plate of the FIG. 5 embodiment (second embodiment);

FIG. 8 illustrates the hermetically-sealed coil structure of the FIG. 5 embodiment of the invention or the top view of the middle dielectric plate of the second embodiment;

FIG. 9 depicts a top facial view of the top vacuum plate of the FIG. 5 embodiment, indicating the feedthroughs for electrical RF, gas injection, and cooling water;

FIG. 10 shows a cross-sectional view of a modified version of the second multi-zone ICP embodiment where the distance between the vacuum plate and the ICP housing has been increased in order to enable smaller minimum ICP source to substrate spacing for enhanced ICP process throughput rate;

FIG. 11 shows a second cross-sectional view of the modified version of the second ICP embodiment of FIG. 10 mounted on a vacuum process chamber for high-throughput plasma-assisted processing applications;

FIG. 12 shows a first cross-sectional view of another (third) embodiment of the invention;

FIG. 13 includes a second cross-sectional view of the FIG. 12 embodiment (third embodiment);

FIG. 14 provides a cross-sectional view of the middle dielectric plate of the FIG. 12 embodiment (third embodiment);

FIG. 15 is a first cross-sectional view of yet another embodiment of the present invention (fourth embodiment);

FIG. 16 provides a second cross-sectional view of the FIG. 15 embodiment of the invention (fourth embodiment);

FIG. 17 illustrates a top view of the vacuum plate of the FIG. 15 embodiment (fourth embodiment), indicating various feedthroughs for process gas inlets, coolant flow, and electrical connections;

FIG. 18 shows a bottom view of the vacuum plate appearing in FIG. 17, indicating the radial low-reluctance magnetic rod positions;

FIG. 19 depicts a cross-sectional view of the bottom dielectric plate for the FIG. 15 embodiment of the invention (fourth embodiment);

FIG. 20 is a top view of the bottom dielectric plate of FIG. 19;

FIG. 21 provides a bottom facial view of the top dielectric plate of the FIG. 15 embodiment of the present invention (fourth embodiment);

FIG. 22 shows the overall schematic view of a vacuum process chamber using the multi-zone ICP source structures of this invention (example shows a three-zone ICP configuration);

FIG. 23 illustrates the schematic diagram of a two-manifold gas distribution arrangement for the ICP source of FIG. 17 where the input gases are partitioned into two groups;

FIG. 24A shows a schematic electrical wiring diagram of a three-zone ICP configuration for the multi-zone ICP source of FIG. 17;

FIG. 24B shows a schematic electrical wiring diagram of a two-zone ICP configuration for the multi-zone ICP source of FIG. 17;

FIG. 25A shows a schematic electrical wiring diagram of a three-zone ICP configuration for a single RF power supply based on an adjustable capacitor array;

FIG. 25B shows a schematic electrical wiring diagram of a three-zone ICP configuration for a single RF power supply based on an adjustable air-core transformer; and

FIG. 26 shows a schematic diagram of a planar ICP source assembly according to one hermetic sealing fabrication method of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Preferred embodiments of the present invention are illustrated in the FIGUREs like numerals being used to refer to like and corresponding parts of the various drawings.

The embodiment of the present invention that FIGS. 1 through 4 describe is a hermetically-sealed multi-zone (HMZ) ICP source for various high-density plasma applications, including plasma etch, PECVD, surface cleaning, plasma hydrogenation, and other plasma-assisted fabrication processes. The concepts of the present invention apply not only to a two-zone ICP source, but also to a multi-zone source with any number of ICP excitation zones (2, 3, 4, and more). Moreover, the preferred embodiment of this invention is for implementation of the HMZ ICP source inside the ICP vacuum process chamber in order to eliminate the need for a dielectric vacuum window and to enable implementation of an all-metal-seal ICP source and process chamber for improved vacuum integrity by reducing the chamber vacuum base pressure. It is, however, understood that the HMZ ICP source of this invention can also be implemented outside the vacuum chamber using a dielectric vacuum window for separating the source from the process chamber.

The HMZ ICP source of FIGS. 1 through 4 provides a design in conjunction with a six-zone showerhead gas injector. The HMZ ICP source, however, is also compatible with the use of either a single-zone showerhead or a multi-zone showerhead with any number of independently controlled showerhead zones (e.g., from one to ten zones). Some applications such as surface cleaning may require only a single-zone showerhead while other applications such as PECVD may benefit from using multiple showerhead zones for improved process uniformity control via multi-zone gas flow adjustment. The multi-zone showerhead feature allows radial control of the process gas mass transport profile which is particularly useful for uniform PECVD applications. Moreover, using the multi-zone showerhead, the source can be used for injection of multiple gases without premixing the gases. As a result, mixing of multiple gases occurs in the plasma process environment and not inside the delivery gas lines or inside the ICP source. Separation of multiple process gases, such as in a binary gas system in CVD applications, can eliminate the possibility of gas phase nucleation and particulate generation inside the showerhead. For instance, in a PECVD process used for silicon dioxide deposition, the process gas system may comprise SiH_4 and N_2O. Using the multi-zone showerhead arrangement of this invention, these gases can be separated and injected as a binary system into alternating adjacent showerhead zones.

With this introduction, more particular attention is now drawn to FIG. 1. FIG. 1 shows HMZ ICP source **100** that includes water-cooled or temperature-controlled metallic top vacuum plate **102**, which may be formed of stainless steel or aluminum, that adjoins top dielectric plate **104**. Top dielectric plate **104** is hermetically sealed or bonded to middle dielectric plate **106** which itself hermetically bonds to showerhead injector plate **108**. Optical plug (or window) **110** passes through metallic top plate **102**, top dielectric plate **104**, middle dielectric plate **106**, and showerhead injector plate **108**, and provides an optical viewport to the entire wafer surface throughout the fabrication process. The optical viewport can also be used for monitoring of the plasma process parameters using a suitable optical sensor, such as spatially resolved plasma emission sensor.

Metallic top plate **102** includes numerous feedthroughs or penetrations, some of which are for coolant (e.g., water) flow purposes, some are for ICP gas injections, and the remaining ones are for electrical RF feedthroughs. For example, the first set of showerhead gas inlets **112**, **114**, and **116** pass through metallic top plate **102**, are bonded to the holes within the top dielectric plate **104**, and feed into the holes within the middle dielectric plate **106** in order to inject the process gases into respective showerhead zone dispersion cavities **118**, **120**, and **122**. Showerhead zone cavities **118**, **120**, and **122** direct process gases to the rings of injection holes **124**, **126**, and **128** of showerhead injector plate **108**. Likewise, showerhead inlets **130**, **132**, and **134** also pass through metallic top plate **102**, are bonded to holes within the top dielectric plate **104**, and feed into the holes within the middle dielectric plate **106** in order to inject the process gases into respective showerhead zone dispersion cavities **136**, **138**, and **140**. From the associated showerhead zone cavities **136**, **138**, and **140**, plasma process gases pass through and out of several rings of gas injection holes **142**, **144**, and **146** of showerhead injector plate **108**.

Also penetrating through vacuum base plate **102** are a plurality of electrical RF feedthroughs including RF feedthroughs **150** and **152**. RF feedthrough **150**, for example, connects through RF feedthrough connection **154**, passes through channel **156** of metallic top plate **102**, continues through top dielectric plate **104**, and continues into cooling water channel **160** of middle dielectric plate **106** until it contacts ICP antenna RF coil segment **173** (which is part of a two-zone HMZ ICP source **100** arrangement).

Hermetically-sealed ICP source **100** includes two zones of cooling (such as water cooling) to remove heat generated by the ohmic power losses due to RF power delivery and ICP plasma generation process. The first zone includes inlet channel **162** that passes through metallic top plate **102** and is bonded to the top dielectric plate **104** for providing cooling water to cooling water channel **164** of middle dielectric plate **106**. Middle dielectric plate **106** provides internally a cooling path by which water may enter, for example, cooling channel **164**, pass through to cooling channels **160** and ultimately enter cooling channel **166**. From cooling channel **166**, cooling water exits from the ICP source through outlet **168**. Outlet **168** receives the cooling water from the zone 1 cooling channels and permits continuous flow of cooling water from cooling water inlet **162** through cooling channels **164**, **160**, and **166** with a continuous heat removal action. In the first zone of hermetically-sealed ICP source **100**, zone-1 RF contact **170** provides a path by which an RF current may flow through each of plated (or molded or inserted) coil segments **172**, **173**, and **174** of zone-1.

In completing the description of hermetically-sealed ICP source **100** as depicted in FIG. 1, in metallic top plate **102** are cooling channel feedthroughs for receiving cooling water including cooling channel **176** connected to zone-1 inlet channel **162** (via an in-line insulating ceramic tube insert), and cooling channel **178** connected to zone-1 outlet channel **168** (via an in-line insulating ceramic tube insert for electrical isolation). Cooling water inlet **180** connects to in-line insulating ceramic tube insert **182** for providing cooling water to cooling channel **184** of zone-2 of hermetically-sealed ICP source **100** and its surrounding region. In middle dielectric plate **106**, coolant passes to cooling water channel **188** for cooling coil segment **190** and its surrounding region. From cooling channel **188**, cooling water flows in middle dielectric plate **106** to cooling channel **192** for cooling coil segment **194** of zone-2 of the hermetically-sealed ICP source and its surrounding region. The cooling water subsequently flows out of the zone-2 coils via coolant outline **197**.

In middle dielectric plate **106**, cooling water channels **164**, **160**, **166**, **184**, **188**, and **192** have been shown with progressively greater depths. This configuration enables vertical contouring of respective coil segments **174**, **173**, **172**, **186**, **190**, and **194**. This ICP antenna contouring (convex or concave contouring) provide an additional design parameter to optimize the ICP uniformity performance. Showerhead **108** is made of an electrically insulating and thermally conductive material, preferably formed of a ceramic material such as aluminum nitride (AlN), aluminum oxide (Al_2O_3), or boron nitride (BN). Similarly, the top and middle dielectric plates **104** and **106** should be made of a suitable electrically insulating and thermally conducting material such as AlN, Al_2O_3, or BN. As appropriate, the contacting interfaces between the plates of hermetically-sealed ICP source **100** are hermetically bonded or fused (preferably using a thermal bonding process) or otherwise connected (such as with a high-temperature cured UHV-compatible epoxy) in order to establish a sealed ICP antenna encapsulation housing for ultraclean plasma processing. For example, metallic top vacuum plate **102** and top dielectric plate **104** are fused or hermetically bonded together using a thermal bonding (e.g, with indium) or epoxy bonding pro-

cess. Top dielectric plate **104** and middle dielectric plate **106** are also bonded together at their contact interface junctions. Similarly, middle dielectric plate **106** and showerhead injector plate **108** are also bonded together at their contact junctions. All four plates (metallic plate **102** and ceramic plates **104**, **106**, and **108**) can be bonded together using a single thermal bonding process using indium or another suitable bonding or brazing material.

Optical plug **110** provides a viewpoint for probing or viewing the plasma process environment. On top of optical plug **110** is view port **198** which is connected or sealed (using a metal or wire seal) to metallic top plate **102** through hermetically sealed flange **200**. The hermetically-sealed ICP source employs a water-cooled (or gas-cooled) metallic (stainless steel) top vacuum plate **102** to support the ICP source inside the plasma process chamber and to enable establishing a UHV base pressure of less than 1×10^{-8} Torr. Metallic top plate **102** also provides all the necessary feedthroughs (RF, gas inlets, and cooling water inlets/outlets for the ICP coil channels), and provides a vacuum seal (e.g., using a metal seal) to the ICP process chamber. The metallic top vacuum plate **102** cooling may be performed either indirectly using the ICP source coolant (water) flowing through the coil channels in the ceramic housing, or directly using separate embedded cooling channels inside the metallic vacuum top plate **102** itself.

Hermetically-sealed ICP source **100** of the FIG. 1 embodiment, therefore, consists of two RF power sources (for a 2-zone ICP arrangement), 12 electrical RF feedthroughs for 6 coil segments and six pairs of electrical contacts, four coolant feedthroughs (including two inlets and two outlets), and six process gas inlets (assuming six injection zones). However, for the same two-zone ICP coil configuration of hermetically-sealed ICP source **100**, the number of external coolant feedthroughs can be reduced to two by connecting the zone-1 and zone-2 water channels in series within the ICP ceramic housing middle dielectric plate.

FIG. 2 shows a top view of the middle dielectric or ceramic insulator plate comprising the two-zone antenna configuration for ICP antenna **202** of the present embodiment. Multi-zone ICP antenna **202** is fabricated within middle dielectric plate **106** of hermetically-sealed ICP source **100**. Middle dielectric plate **106** is made of a thermally conductive and electrically insulating material such as AlN, Al_2O_3, or BN. Formed in ICP source middle dielectric plate **106** are two RF antenna zones for ICP generation that are conceptually differentiated by dash line **206**. For example, that portion of ICP antenna **202** outside of dash line **106** corresponding to the antenna segments **172**, **173**, and **174** forms the zone-1 antenna **208**, while that portion within dash line **206** containing the antenna segments **186**, **190**, and **194** forms the zone-2 antenna **210**.

As FIG. 2 further indicates, at the center of zone-2 antenna **210** appears the feedthrough hole for optical viewport plug **110**. Zone-1 or outer zone antenna **208** begins with outer zone-1 RF contact **211** that connects to plated (or a combination of sputtered and plated, or inserted broken ring) coil segment **172** that was originally introduced in FIG. 1. The coil segment **172** is formed in a circular path as a broken ring and continues to RF terminal contact **212**. The coolant groove **164** over outer zone coil segment **172** is connected in series to the adjacent outer zone coils segment **173** coolant channel **160** via jumper water channel **214** of middle dielectric plate **106**. Connecting to unplated (electrically insulating) jumper water channel **214** is RF terminal contact **150** (FIG. 1) which also connects to ICP coil segment **173**.

ICP coil segment **173** is also formed as a broken ring and takes a circular path around middle dielectric plate **106** to connect to RF terminal contact **216**. The coolant groove **160** of the outer zone segment **173** is connected in series to the coolant groove channel **166** of the outer zone segment **174** via unplated or conductor-free coolant channel **218** between the RF contacts **216** and **220**. The RF terminal contact **220** connects to outer zone plated (or conductor covered) coil segment **174** that takes a broken ring circular path to outer zone RF contact **170**.

The inner zone or zone-2 antenna **210** begins at RF contact **222** which connects to inner zone coil segment **186**. Coil segment **186** runs in a circular pattern as a broken ring and connects to RF terminal contacts **222** and **224**. The coolant groove channel **184** of the inner zone coil segment **186** connects to the inner zone adjacent coil segment coolant groove channel **188** via unplated (conductor free or electrically insulating) coolant channel jumper **226**. The inner zone coil segment **190** runs as a broken ring (using plated or inserted conductor) underneath coolant groove channel **188** between RF contacts **227** and **228**. The coolant groove channel **188** of the inner zone coil segment **190** connects to the inner zone coolant groove channel **192** of the coil segment **194** via unplated (conductor free or electrically insulating) coolant channel **230**. The RF contacts **224** and **227** are externally connected together via an RF capacitor. Similarly, the RF contacts **228** and **232** are linked together via another external RF capacitor. These external capacitor connections (on the atmospheric side of the ICP source) create a 3-turn inner zone coil with two series capacitors for reduced induced voltage. The inner zone RF power supply contacts are the RF contacts **222** and **234**. The RF contact **234** connects to coil segment **194** which surrounds optical viewport plug **110** as a broken ring and connects to inner zone RF contact **232**. As can be seen in ICP antenna **202**, zone-2 antenna portion **208** may operate independently of zone-1 antenna **210** using two separate RF power supplies.

The hermetically-sealed ICP source **100** antenna **202** of FIG. 2, therefore, contains two inductive antenna zones each with three turns. The same design may be arranged with a different external wiring configuration in order to establish, for instance, a three-zone ICP source with two coil turns in each zone. Although a three-zone ICP configuration or another design with more zones is well within the scope of the present invention, the remainder of this description focuses on a two-zone ICP source design configuration. It should be also noted that the design of FIGS. 1 through 4 is electrically configurable externally without any hardware design modifications within the ICP source structure.

As FIG. 2 shows, six pairs of electrical RF contacts are made to the six coil turns using ultrahigh vacuum (UHV) compatible electrical RF feedthroughs in metallic top plate **102** and spring-loaded (or soldered) electrical wires attached to the coil segments. These 12 electrical contacts connect to the multi-zone segment terminals **211** (Z_{11}), **212** (Z_{12}), **150** (Z_{13}), **216** (Z_{14}), **220** (Z_{15}), **170** (Z_{16}), **222** (Z_{21}), **224** (Z_{22}), **227**, (Z_{23}), **228** (Z_{24}), **232** (Z_{25}), and **234** (Z_{26}) For a two-zone hermetically-sealed ICP source **100** configuration with three coil turns in each zone, the external electrical wiring and capacitor connections is as follows: The electrical RF terminal contacts **211** (Z_{11}) and **170** (Z_{16}) connect to the first zone RF (e.g., 13.56 MHZ) power supply. External capacitor terminal contacts **212** (Z_{12}) and **150** (Z_{13}) connect via an external RF capacitor. External capacitor terminal contacts **216** (Z_{14}) and **170** (Z_{15}) connect via a second RF capacitor. This completes the formation of ICP zone-1 antenna **208** comprising three coil turns and two external

capacitors in series. ICP zone-2 antenna **210** is configured by connecting the electrical RF terminal contacts **222** (Z_{21}) and **234** (Z_{26}) to the second RF power supply. One external RF capacitor is used to connect RF terminal contacts **224** (Z_{22}) and **227** (Z_{23}) while another RF capacitor links RF terminal contacts **228** (Z_{24}) and **232** (Z_{25}) together. A phase shifter/controller may be used between the two ICP RF power supplies in order to control the phase angle between the two power sources. Moreover, another phase shifter may be used to control the phase angle between any of the ICP RF sources and the substrate bias RF power supply. If desired, the ICP source **100** design of FIGS. **1** through **4** may be externally configured for operation as an n-zone ICP source with n=1, 2, 3, 4, or even larger. The number of coil turns in each zone can also be selected by the design of the external wiring and series RF capacitor arrangement.

FIG. **3** describes in more detail the construction of top dielectric plate **104** including the bonded ICP feedthroughs. Top dielectric plate **104** may be formed of a thermally conductive and electrically insulating ceramic material such as aluminum nitride (AlN), boron nitride, or even aluminum oxide. Top dielectric plate **104** has, in the present embodiment, several bonded feedthroughs for two antenna zones and six showerhead zones. In the left-hand side feedthrough section **240**, ICP antenna zone-1 electrical feedthrough **150** connects to one of the RF contacts in zone-1 RF antenna **208** of FIG. **2**. There are six electrical RF feedthroughs for the ICP zone-1 segments and another six electrical RF feedthroughs for the ICP zone-2 segments. In the right-hand side feedthrough section **242**, ICP antenna zone-2 electrical feedthrough **152** connects to one of the RF contacts in zone-2 RF antenna **210** of FIG. **2**. Top dielectric plate **104** also includes the necessary feedthrough inlets **112**, **114**, **116**, **130**, **132**, and **134** for gas flow connections to the showerhead injector dispersion cavities (six showerhead zones are shown). Similarly, top dielectric plate **104** permits flow of cooling water through bonded tubes for zone-1 coolant inlet **162** and zone-1 coolant outlet **168**. Top dielectric plate **104** also includes two bonded tubes for zone-2 coolant inlet **180** and zone-2 coolant outlet **197**. Except for the RF feedthroughs, all the bonded feedthroughs (gas injection inlets and coolant inlet/outlet tubes) are flushed against the bottom surface of the top dielectric plate **104** (or they can be bonded to the dielectric holes by partial feeding the tubes into a fraction of the dielectric plate thickness).

FIG. **3**, therefore, illustrates top dielectric plate **104** with all the bonded tubings (for gas injection and water cooling) and electrical RF connectors. For an ICP source with a multi-zone injector, multiple gas injection tubes are used whereas for an ICP source with a single-zone showerhead, a single gas injection tube can be used. The FIG. **3** design also shows four water cooling tubes **162**, **168**, **180**, and **197**. If desired, the number of water cooling feedthrough tubes can be reduced to two by interconnecting the ICP antenna cooling channels in series internally by added coolant groove segments (w/o metallization or conductor jumpers/links) between the broken rings in the middle dielectric plate containing the ICP antenna grooves containing the conductor grooves.

FIG. **4** illustrates a facial bottom surface view of the middle dielectric plate **106** of the present embodiment. This dielectric plate surrounds optical plug **110** and may be formed of a thermally conductive and electrically insulating ceramic material such as aluminum nitride (AlN), boron nitride (BN), or even aluminum oxide (Al_2O_3). In the present embodiment, ceramic showerhead **108** includes six gas injection zones, each corresponding to one of the gas dispersion cavities embedded in the middle dielectric plate **108** and shown in FIG. **4**. These gas dispersion cavities are shallow circular grooves formed in the middle dielectric plate **106** and connected to the gas injection inlets. In particular, inner gas dispersion cavity ring **140** receives process gas via gas injection inlet **134** and uniformly directs the process gas to the inner zone of showerhead **108** injection holes **146**. Second gas dispersion cavity **138** receives process gas via gas injection inlet **132** and uniformly distributes the process gas to the second zone of showerhead injection holes **144**. Third gas dispersion cavity **136** receives process gas from gas injection inlet **130** and distributes the process gas to the third zone of showerhead injection holes **142**. Fourth gas dispersion cavity **122** receives process gas through inlet **116** and guides the process gas to the fourth zone of showerhead injection holes **128**. Fifth gas dispersion groove **120** receives process gas from inlet **114** and distributes the process gas to the fifth zone of showerhead injection holes **126**. Sixth gas dispersion cavity **118** receives process gas from inlet **112** and directs the process gas to the outer zone of showerhead injection holes **124**.

The vacuum, water, and process gas seals for hermetically-sealed ICP source **100** may be established either using bonded junctions that are formed using a thermal bonding process or, alternatively, elastomer O-ring seals. Thermal bonding using a suitable low melting point metal or metal alloy is a preferred method for establishing hermetic seals in ICP source **100** since a bonded structure eliminates the possibilities of process contamination, base pressure degradation, and outgassing problems associated with elastomer O-ring seals. Indium, indium alloys, or other suitable bonding materials may be used for formation of the bonded ICP structure. An alternative to metal-based thermal bonding is hermetic bonding using a thermally cured epoxy material.

As shown in FIG. **1**, besides the metallic top plate **102**, ICP source **100** housing comprises a stack of three electrically insulating disks. As described earlier, these disks may be made of a ceramic material, preferably a thermally conductive ceramic material such as aluminum nitride (AlN), boron nitride (BN), alumina (Al_2O_3), or even a plasma-resistant polymer based material, such as Vespel. Due to their high-temperature stability, ceramic materials work well for the ICP source **100** structure when assembled using a thermal bonding process. This is due to the fact that the thermal bonding processes using various bonding materials may require bonding temperatures in the range of 200° C. to 600° C. A bonding temperature of <300° C. can be used using tin (Sn) or indium (In) or their alloys as the metallic bonding material. Moreover, the epoxy bonding processes usually employ thermal cure temperatures <300° C.

The use of optical viewport **198** of ICP source **100** is optional and this viewpoint may be positioned at the center of hermetically-sealed ICP source **100**. Optical plug or light pipe **110** may be made of a suitable optically transmissive light pipe material such as quartz or sapphire for implementation of a real-time in situ sensor. Viewport **198** provides a suitable wafer view for integration of a full-wafer interferometry sensor for real-time rate and process uniformity control. This viewport can also be used for integration of other types of plasma sensors such as a single-wavelength or spectral plasma emission sensor. The ICP source design concepts of this invention are applicable to both planar and contoured ICP coil designs. For 8" wafer processing, metallic top plate **102** may have a diameter of 14" to 20". The vacuum plate diameter could be as much as 20" as is the case of the Universal Plasma Module (UPM) manufactured by

CVC Products of Rochester, N.Y., which has an internal chamber diameter of 18". Metallic top plate 102 may have thickness in the range of ¼" to 1" to provide sufficient mechanical strength for use on a vacuum process chamber.

Top dielectric plate 104, middle dielectric plate 106, and showerhead 108 form a stack of three bonded ceramic (AlN, Al_2O_3 or BN) or polymer-based (e.g., Vespel) disks as the main ICP antenna housing of the ICP source 100. The showerhead plate 108 is a relatively thin plate (e.g., a thickness of ⅛" to ¼") with an array of rings of circular holes (0.5 mm to 1 mm diameter holes) forming a six-zone showerhead configuration. The central opening 109 of showerhead 108 preferably has a diameter in the range of 0.50" to 1.5" to receive viewport optical plug 110. Showerhead 108 is thermally bonded (or connected using an elastomer O-ring seal) to the middle dielectric plate 106 which contains the ICP RF antenna coil segments and cooling water channels.

The ICP source embodiment depicted in FIGS. 1 through 4 shows that only the bottom surface of the ICP antenna grooves or the coolant channels contain conductor channels to form the ICP coil segments. If desired, a metallization process (e.g., electrochemical plating or a combination of sputtering and electroplating depositions) may be used to form the conductor channels by coating not only the cooling channel bottom surfaces, but also the groove sidewalls for reduced RF resistance. For 8" wafer processing, the optimum ICP source ceramic housing diameter is 10" to 14" and preferably 12". If desired, the ICP antenna conductor segments may be prefabricated from a suitable material such as aluminum or copper and subsequently inserted in the designated antenna channels.

FIG. 5 shows a first cross-sectioned view of an alternative or second embodiment of the present invention as ICP source 300. This alternative embodiment demonstrated in FIGS. 5 through 9 shows a planar hermetically-sealed multi-zone (HMZ) ICP source design without any contouring of the ICP antenna or the dielectric housing. HMZ ICP source 300 includes metallic (e.g., stainless steel) vacuum plate 302 that attaches to top dielectric plate 304 and provides vacuum seal to plasma process chamber (not shown). Top dielectric plate 304 contacts vacuum plate 302 either using hermetic bonded junctions or elastomer O-ring seals (301 and 303). Top dielectric plate 304 attaches to middle dielectric plate 306 via junctions 305 and 307 which are formed either using hermetic bonding or O-ring seals. Moreover, middle dielectric plate 304 is sealed against showerhead plate 308 using bonded junctions 309 or a single outer O-ring seal. Optical viewport 310 includes optical plug 110 or optical window 198 which is hermetically sealed to flange 200 which is secured to vacuum plate 302 using a metal or wire seal. In addition, vacuum plate 302 includes numerous embedded coolant channels to prevent heating of the plate 302 by the ICP RF antenna. Multi-zone process gas injection inlets 314 pass through feedthrough holes 312 in vacuum plate 302, pass through top dielectric plate 304, and continue to middle dielectric plate 306 to provide process gas to showerhead zone dispersion cavities 316. Showerhead zone dispersion cavities 316 receive process gases from the showerhead inlets 314 and provide uniform gas distribution to showerhead injection hole, 318.

Besides the gas dispersion cavities 316 and bonded gas injection inlets 314, the lower dielectric plate 306 also includes the ICP source antenna segments 328 (eight separate segments shown). The ICP source antenna segments 328 are formed by filling the grooves formed on the top surface of the middle dielectric plat using a plating, evaporation, sputtering, or a casting/molding process. An alternative method is to prefabricate the ICP source antenna segments from a suitable material such as aluminum or copper and subsequently insert them in the middle plate antenna cavities. The ICP antenna segments 328 may also be made of other metallic materials such as refractory metals. The top dielectric plate 304 contains coolant grooves 320 formed over the ICP antenna coil segments. These coolant channels connect to external coolant inlet/outlet channels and prevent heating of the ICP source housing during its operation. The ICP structure of FIG. 5 consists of a stack of four plates (one metal and three dielectric plates) which are connected together either using an O-ring-free hermetic bonding process (using indium or another material as a bonding agent or using thermal epoxy bonding) or using elastomer O-ring seals. The dielectric plates may be made of a suitable ceramic (AlN, BN, or Al_2O_3) or polymer (e.g., Vespel) material. The gas injection inlets 314 (made of stainless steel tubes) are externally connected to one or more gas manifolds for single-zone or multi-zone showerhead operation.

FIG. 6 shows a different cross-sectional view of multi-zone ICP source 300 of FIG. 5 along a cross-sectional plane which is perpendicular to that of FIG. 5. Components previously described in connection with FIG. 5 are identical to those appearing in FIG. 6. FIG. 6 shows additionally, however, cooling water (or any coolant) inlet 321 for directing cooling water to the cooling water channels 320 which are connected in series by coolant jumpers within top dielectric plate 304 to cooling water outlet 322. To connect various components of multi-zone ICP source 300, the present embodiment uses several bonded junctions 324 using indium or another suitable bonding material. FIG. 6 also shows spring-loaded or soldered electrical feedthrough connectors 313 for various ICP antenna coil segments. For instance, sixteen electrical connectors are used for the ICP source structure with eight (antenna) coil segments.

FIG. 7 shows one embodiment of middle dielectric plate 306 that appears in the FIG. 5 embodiment. As previously mentioned, middle dielectric plate 306 is made of a suitable thermally conductive and electrically insulating substrate material which includes passageway 326 for receiving optical plug 110 of optical viewport 198 (or for providing an optical view of the plasma chamber and/or wafer surface) for sensor-based process monitoring and control applications. In a circular broken-ring configuration, numerous aluminum-filled or copper-filled (or in general electrical conductor filled) grooves or trenches appear for receiving radio frequency electrical power and serving as multi-zone ICP antenna portions 328. Also within middle dielectric plate 306 are multiple showerhead zone dispersion cavities 316. Plate bonding junctions 324 are formed on the top and bottom surfaces of middle dielectric plate 306 in order to establish hermetic seals for the multi-zone ICP structure. Middle dielectric plate 306 may be made of a thermally-conducting, electrically-insulating ceramic disk such as a 12" diameter disk of aluminum nitride, aluminum oxide, or boron nitride. In the embodiment of FIG. 7, conductor-filled (such as aluminum-filled or copper-filled) trenches 328 take the form of eight planarized coil turns in the shape of broken rings. The hermetically-sealed multi-zone ICP antenna segments become *an integral part* of the middle dielectric plate 306. These antenna segments may be separately fabricated and subsequently inserted in the middle dielectric plate trenches 328 prior to hermetic sealing or bonding of the multi-zone ICP structure. The showerhead zone dispersion cavities 316 form continuous concentric rings around optical

plug hole 326 on the bottom surface of the middle dielectric plate 306. Plate bonding junctions 324 can be formed within hermetic sealing trenches and form continuous concentric rings between the adjacent gas dispersion cavities on the bottom surface and multi-zone ICP antenna segments on the top surface. The bonding material may be, for example, aluminum, tin, aluminum silicon, indium, or other compatible materials such as brazing materials or thermally conductive epoxy materials.

FIG. 8 shows a facial top surface view of middle ceramic plate 306 to illustrate the hermetically sealed antenna structure of the embodiment of FIG. 5. In particular, top planarized surface 330 includes, in the FIG. 8 embodiment, nine concentric and continuous rings of hermetic bonding joints 324 for forming a hermetic bond between middle dielectric plate 306 and top dielectric plate 304. Each hermetic bonding joint 324 preferably includes a circular shallow groove or trench filled with a suitable bonding material such as indium. To form the multi-zone coil configuration of FIG. 8, eight (or any other desired number of) inductive coil segments 328 are employed which are in the form of concentric broken rings separated from one another by hermetic sealing trenches 324. Multi-zone coil segments 328 fill the designated substrate grooves and may be formed of aluminum or another electrically conductive material such as copper.

Although eight coil segments are shown in FIG. 8, fewer or more number of inductive segments may also be used for a specific application, depending on the multi-zone ICP uniformity control requirements and substrate size to be processed. Each segment cross sectional area may be approximately 0.25 inches to 0.5 inches wide with a thickness of 0.001 inches to 0.120 inches. Each concentric broken ring 328 includes two electrical contact terminals 332 and 336 for connecting to an external radio frequency power source or for external interconnection of the antenna coil segments to each other via RF capacitors. In one example of the FIG. 8 embodiment, middle ceramic plate 306 has a 12-inch diameter with a 0.25 inch thickness for eight-inch wafer processing. The plate may be made of aluminum nitride (AlN), boron nitride (BN), aluminum oxide (Al_2O_3), or another suitable material.

FIG. 9 illustrates a top facial view of metallic vacuum plate 302 for the FIG. 5 embodiment. Top surface 349 of metallic top plate 302 shows feedthrough channels 312 that permit passage of multi-zone showerhead process gas inlets 314. The designations of showerhead inlets appearing in FIG. 9 are as follows. SH-81 and SH-82 are two half-zone showerhead gas inlets for the outermost injection zone holes 318 for showerhead injector plate 308 of FIG. 5. Each successive designation SH-71 and SH-72, SH-61 and SH-62, SH-51 and SH-52, etc., down to SH-11 and SH-12, indicate half-zone pairs of showerhead inlets for the associated showerhead injection zone grooves 318 down to the innermost showerhead injection zone holes 318 closest to the opening for optical plug 110. For the particular configuration shown in FIG. 5, the gas injection inlets (SH-11/SH-12 to SH-81/SH-82) can be externally configured using gas manifolds such that the multi-zone ICP source showerhead may operate as an n-zone showerhead with "n" selectable between 1 and 8. In addition to showerhead inlets appearing on top surface 340 there also appears ICP source coolant inlet 322 and ICP source coolant outlet 321. ICP source coolant inlet 322 provides coolant (e.g., cooling water) flow to coolant channels 320 of top dielectric plate 304. Coolant inlet 346 and coolant outlet 348 provide a coolant flow for cooling channels embedded within metallic vacuum plate 302.

In FIG. 9, metallic top plate 302 also includes on top surface 340 external RF capacitor components associated with partitioned ICP source zones 350, 352 and 354 (example shown for a three-zone ICP source arrangement). These external RF capacitors include RF capacitors 356 through 364. In the embodiment of FIG. 9, three radio frequency circuits, including RF power supply RF_1, RF power supply RF_2, and RF power supply RF_3 provide RF electrical power signals to the multi-zone ICP source coils via the external capacitor circuitry. In particular, RF power supply RF_1 connects to the outer ICP zone via external RF capacitor circuit 350. RF power supply RF_2 connects to the middle ICP zone via external power RF capacitor circuit 352. Also, external RF capacitor circuit 354 delivers power from RF power supply RF 3 to the inner ICP zone.

FIGS. 5 through 9, therefore, demonstrate an alternative embodiment for hermetically-sealed multi-zone ICP source 300 that has many features similar to the design described earlier. The alternative design of FIGS. 5 through 9, however, is a completely planar hermetically-sealed multi-zone ICP source without any contouring of the ICP coil segments or the dielectric housing. In this design, middle dielectric plate 306, which may be made of one of several dielectric materials such as alumina or aluminum nitride, contains fully metallized grooves, forming the bonded multi-zone coil structure shown in FIG. 8. The FIG. 8 embodiment shows eight coil segments, although any number of segments (e.g., two to ten) may be used in the design. The middle dielectric plate 306 also includes bottom gas grooves 316 for gas injection. Bottom gas grooves 316 can be formed as continuous rings which connect to the bonded gas injection tubes coming from the metallic top plate 302 feedthroughs.

In this design, hermetically-sealed multi-zone ICP source 300 with its eight coil segments employs an eight-zone showerhead 308 with sixteen gas inlets 314. Each showerhead 308 zone has two gas injection inlets 314 (e.g., SH-11 and SH-12 inlets connected to the showerhead zone 1) for enhanced process uniformity. Each showerhead 308 zone may, however, use only one gas inlet 314 as long as the showerhead 308 gas grooves or gas dispersion cavities 316 provide sufficient gas flow conductance for axisymmetric gas injection through the injector plate holes 318. For a single-zone showerhead (e.g., when ICP is used for low-pressure surface preparation/cleaning applications), only a single gas inlet is required. This can be accomplished by using a gas manifold which connects to al the gas inlets SH-11/SH-12 through SH-81/SH-82. A multi-zone gas inlet configuration, however, provides the flexibility to configure the gas injection as single-zone or multi-zone injection by appropriate external plumbing and gas manifolding.

For the design shown FIGS. 5 through 9, the multi-zone ICP source water cooling channels are included in top dielectric plate 304. Top dielectric plate 304 also contains all the ICP antenna electrical feedthroughs as well as the bonded gas injection inlets and water cooling inlet/outlet tubes. If the entire multi-zone ICP source 300 structure is hermetically bonded to the stainless steel vacuum plate and if the ICP dielectric housing plates (three plates) are made of a relatively high thermal conductivity material such as aluminum nitride (AlN) or boron nitride (BN), the cooling channels and the associated cooling feedthroughs may be eliminated from the top dielectric plate. This is possible because the ICP housing can be effectively cooled using the water-cooled stainless steel vacuum plate. A thermally conductive bonded hermetically sealed junction between the metallic vacuum plate and the top dielectric plate will

facilitate heat transfer from the ICP antenna to the water-cooled vacuum plate. As shown in FIG. 9, this multi-zone ICP source can be externally configured as an n-zone source with n=1, 2, 3, 4, or even more (up to 8 for this particular design). The configuration shown in FIG. 9 indicates a three-zone ICP arrangement with three individually controlled RF power supplies.

The external RF capacitors 356 through 364 reduce the induced reactive voltage, resulting in negligible capacitive coupling and sputtering of the chamber and ICP source materials. In the configuration shown in FIG. 9, the eight-segment ICP source has been externally partitioned and configured as a three-zone plasma source. The outer three coil segments in conjunction with two external RF capacitors 356 and 358 form the outer ICP zone 350 (using zone-1 power supply RF_1). The middle three coil segments have been grouped together in conjunction with another pair of external RF capacitors 360 and 362 to form the middle or second ICP source zone 352 and are powered by RF power supply RF_2. The inner two coil segments are connected in series via external RF capacitor 364 and form the inner or third ICP zone 354. The inner zone is powered by the third RF power supply (RF_3). These three RF (e.g., 13.56 MHZ) power supplies may also use phase shifters/controllers for enhanced and repeatable process control. Other external wiring arrangements and multi-zone partitioning(two-zone, four-zone, etc.) are also possible using the same ICP source design.

FIG. 10 shows a cross-sectional view of a modified version of the second multi-zone ICP embodiment (shown in FIGS. 5 through 9) where the multi-zone ICP source housing has been lowered with respect to the process chamber vacuum lid or flange by increasing the spacing between the vacuum plate and the ICP housing (by inserting a welded cylindrical metallic extension part between the ICP housing and the vacuum chamber lid). This modified configuration provides a smaller minimum ICP source to substrate spacing for enhanced ICP process throughput rate, particularly in plasma process camber designs where the up/down travel range for the substrate chuck is restricted. FIG. 11 shows a second cross-sectional view of the modified version of the second multi-zone ICP source embodiment of FIG. 10 mounted on a vacuum process chamber for high-throughput plasma-assisted processing applications. As shown in FIG. 11, the recessed ICP housing allows reduced ICP source to substrate spacing for enhanced process throughput. FIGS. 12 through 14 show yet another alternative hermetically sealed multi-zone ICP source 400 embodiment of the present invention. This preferred design is essentially similar to the previous design shown of FIGS. 5 through 9 except for two main differences. FIG. 12 shows alternative hermetically-sealed multi-zone ICP source 400 embodiment in cross sectional view 400 including metallic top plate 402 that attaches to top dielectric plate 404, preferably using a thermal bonding or brazing process. Top dielectric plate 404 attaches to middle dielectric plate 406. Middle dielectric plate 406 bonds to gas injector plate 408. Top vacuum plate 402 includes multiple channels 412 for receiving gas injection inlets 414. Gas injection inlets 414 pass through top dielectric plate 404, are bonded to the top dielectric plate 404, and enter middle dielectric plate 406 where they join showerhead zone cavities 416. Showerhead zone cavities 416 provide process gases to showerhead injection holes 418. Passing through alternative ICP source 400 is optical plug 110 (or an optical viewport) that hermetic metal seal flange 420 connects to top vacuum plate 402. Middle ceramic plate 406 includes distributed cooling water channels 422 that support coil segments 424 on their sidewalls. These coil segments may be formed by plating of the coolant channels.

FIG. 13 shows an alternative cross section of ICP source 400 of FIG. 12. As FIG. 13 indicates, coolant inlet and outlet 426 allow coolant flow through the ICP source housing 400 via the coolant channels 422 formed in the middle dielectric plate 406. Moreover, electrical contact leads 428 allow electrical connections of the multi-zone ICP source cool segments 424 to the external capacitors and RF power supply.

FIG. 14 illustrates in more detail the structure of middle dielectric plate 406 of the present embodiment. As FIG. 14 indicates, RF coil segments 424 line cooling water channels 422. This eliminates the need for formation of deeper coolant channels for cooling RF coil segments. In addition, gas dispersion cavities 416 are formed in the middle dielectric plate 406 for uniform distribution and injection of the process gases via the bottom dielectric plate 408. Opening 426 of middle dielectric plate 406 is of sufficient size to permit passage of optical plug 110 for in-situ plasma process monitoring and control applications.

Consequently, differences between hermetically-sealed multi-zone ICP source 300 of FIGS. 5 through 9 and multi-zone ICP source 400 of FIGS. 12 through 14 include U-shape metallized grooves 422 in the middle dielectric plate, as opposed to the fully filled metallized grooves. As a result of this difference, a second difference is that multi-zone ICP source 400 eliminates the need for fabricating cooling grooves in top dielectric plate 404. This is because the trenches 422 include metallized sidewall and bottom surfaces to form coil segments 424 and can also allow coolant flow for ICP source cooling. This results in a simplified ICP source structure and manufacturing process. As with multi-zone ICP source 300 of FIG. 5, the ICP coil metallization process for multi-zone ICP source 400 may be performed using one or a combination of sputtering and electroplating deposition processes.

Before the ICP source is hermetically bonded to the metallic vacuum plate or chamber vacuum flanges, the ICP coil segments are formed as thin (e.g., 10 μm to 1000 μm) layers of metal (Al or Cu) covering the shallow trench 422 sidewalls and bottom surface. These metallized regions are formed in the shape of broken rings in middle dielectric plate 406 top surface. An alternative embodiment can form the ICP antenna metallized broken rings on the bottom surface of top dielectric plate 304. The vacuum plate or flange 402 has embedded coolant channels in order to perform additional cooling in the ICP source structure.

With multi-zone ICP source 400, it is also possible to place the ICP coil segments 424 between the showerhead 408 and middle dielectric plate 406 by using metallized shallow grooves either on top surface of showerhead plate 408 or on bottom surface of middle dielectric plate 406. Moreover, by using a hermetic bonding process for the overall assembly of the multi-zone ICP source and by providing embedded cooling channels in the top vacuum plate 402, the ICP source cooling can be performed by the top metallic plate 402 and the dielectric coolant grooves 422 can be eliminated. This eliminates the need for top dielectric plate 404 and reduces the overall ICP housing stack to two dielectric plates plus the metallic vacuum lid 402. In this configuration, ICP coil segments 424 may be placed between the gas dispersion trenches 422 on the gas showerhead plate 408. Moreover, they can be used as part of the bonding structure for hermetic sealing of the showerhead

plate 408 to its adjacent dielectric plate 406 which itself is hermetically sealed/bonded to the metallic top plate 402. This simplified multi-zone ICP structure is the fourth embodiment illustrated in FIGS. 15 through 21.

In order to reduce the eddy current RF losses into the metallic top plate 402 and maximize the RF coupling efficiency to the plasma environment, a series of radial strips of a permeable soft magnetic material or a ferromagnetic material (e.g., nickel, iron, etc.) may be placed between the metallic top plate 402 and the multi-zone ICP source 400 housing prior to structural bonding. This may be done by depositing the high-permeability magnetic material on metallic top plate 402 using electroplating techniques. Alternatively, shallow radial grooves may be formed in the metallic top plate 402 on its vacuum side and thin rods of high-permeability material (iron or nickel or another ferromagnetic material) may be inserted within these grooves prior to the hermetic bonding process to seal the multi-zone ICP source 400 housing to metallic top plate 402. These high-permeability magnetic material segments provide radial paths to close the magnetic field lines over ICP coil segments 424, resulting in improved RF coupling efficiency to the internal plasma environment.

FIGS. 15 through 21, therefore, show a hermetically sealed ICP source 500 with six coil segments and six showerhead injection zones. In general, the design shown here is applicable to any number of coil segments 518 and any number of showerhead injection zones 516. Various designs with equal or different numbers of coil segments and injection zones are possible.

Thus, FIGS. 15 through 21 show yet another alternative embodiment of the present invention including vacuum plate 502 that adjoins top dielectric plate 504. Dielectric plate 504 adjoins modified showerhead plate 506. Optical plug or viewport 110 fits within ICP source 500 and is sealed by hermetic metal seals using viewport metallic flange 508. This permits an optical view access through optical plug 110 to the substrate within the plasma process chamber. Vacuum plate or flange 502 includes numerous channels 510 for receiving multi-zone gas inlet tubes 512. Gas inlet tubes 512 go to process gas dispersion channels 514 within top dielectric plate 504. Process gas injection holes 516 connect to process gas dispersion channels 514 for directing process gases through modified showerhead plate 506. In alternative multi-zone ICP source 500, RF coil segments 518 are formed integral to modified showerhead plate or bottom dielectric plate 506. In this configuration, there is no need for additional cooling of RF coil segments 518, since effective cooling of the bonded ICP structure is provided by the embedded coolant channels in the vacuum plate or flange 502.

FIG. 15 shows a stack consisting of three bonded plates. The top plate is a water-cooled stainless steel vacuum plate or flange (typically 14" to 20" in diameter for 200-mm wafer processing (20" diameter for CVC's Universal Plasma Module). Gas inlets 512 in the FIG. 15 embodiment are bonded to the top dielectric plate and flushed/butted against the multi-zone gas dispersion cavities 514. Six cavities 514 are shown along with twelve gas inlet tubes 512.

On the other hand, FIG. 16 illustrates six of the twelve electrical RF rods 520 connected to the multi-zone ICP coil segments 518 on the lower dielectric plate or showerhead plate 506. These RF connector rods are thermally bonded, and/or shrink-fit assembled, inside the upper dielectric plate.

Electrical rods 520 are flushed against the bottom surface of the upper dielectric plate 504 and are subsequently fused or bonded to the electrical terminals on the antenna coil segments that appear on FIG. 20. The bottom and top dielectric plates are bonded together on a continuous ring around the edge region as well as on circular bonded junctions (continuous rings) formed between any pair of adjacent coil segments. This will also ensure excellent thermal contact between the top dielectric plate 504 and bottom dielectric plate 506. The coil segments can provide additional bonding surface area for improved thermal contact.

FIG. 17 shows a top view of vacuum plate 502 of multi-zone ICP source 500. In particular, vacuum plate 502 top view includes vacuum plate coolant inlets 522 and 524 that receive cooling water (or any coolant) for ICP source 500. Cooling water outlets 526 and 528 permit the cooling water to exit multi-zone ICP source 500 for effective heat removal. Gas inlet tubes 512 are shown within channels 514. As is the case with earlier described embodiments, the SH-61 and SH-62 gas inlets correspond to the outermost gas rings of showerhead 506. The decreasing number "SH" associated with the gas inlets 512 correspond to the more inward injection rings of showerhead plate 506. Vacuum plate 502 top surface also includes electrical feedthroughs 530 for connecting to ICP antenna RF coil segments 518 and showerhead plate 506. In the FIG. 17 embodiment, electrical feedthroughs 530 include twelve terminals for six antenna coil segments that connect to the six RF coil segments formed on showerhead plate 506.

For the bonded monolithic structure shown in FIGS. 15 through 21, the water-cooled vacuum plate 502 provides effective cooling of the entire multi-zone ICP source 500 and its associated dielectric housing. This effective cooling is possible since the entire ICP housing bonds together to the metallic vacuum plate. The structural bonding minimizes the thermal resistances between the adjacent dielectric plates 504, 506 as well as between the top dielectric plate 504 and water-cooled vacuum plate 502. Moreover, the multi-zone ICP dielectric housing material can be made of aluminum nitride (AlN) which has a relatively high thermal conductivity on the order of 170 W/m-K. According to FIG. 17, the metallic (stainless steel) vacuum plate or flange provides a number of through holes for various multi-zone ICP source feedthroughs.

FIG. 18 shows a bottom view of vacuum plate 502 of the FIG. 13 embodiment. In particular, the bottom view of vacuum plate 502 shows gas inlets 512 emanating from through channels 514 as well as electrical feedthroughs 530 that pass through vacuum plate 502. In addition, the bottom view of vacuum plate 502 shows embedded radial ferromagnetic rods 532 that are made of a high permeability magnetic material. For example, in one embodiment embedded radial rods 532 may be 8" long by 0.51" wide by 0.25" thick rods of iron or nickel or a more suitable ferromagnetic material with low eddy-current losses that are inserted into same size grooves at the bottom surface of vacuum plate 502. In FIG. 18, there are ten radial rods 532 in vacuum plate 502.

Radial rods 532 that FIG. 18 shows are embedded within grooves in vacuum plate 502 and may be made of a magnetic material such as high permeability iron or nickel and provide radial paths to close the magnetic field lines below the vacuum plate. This will result in a reduction of eddy current losses into the metallic vacuum plate and improves the overall multi-zone ICP source 500 RF power coupling efficiency into the plasma environment. If necessary, radial rods 532 may be replaced with a blanket plated layer of iron or nickel on vacuum plate 502 (in this case the rods and grooves will not be needed).

For the specific design presented here, the vacuum plate has 12 holes for showerhead gas inlet tubes (SH-11, SH-12, SH-21, SH-22, SH-31, SH-32, . . .), and another set of 12 holes for multi-zone ICP electrical connections. Moreover, there is a center hole (0.5" to 1.5" in diameter) which is used for insertion of the optical viewpoint. The metallic vacuum plate (14" to 20" in diameter) has a thickness of 0.25" to 0.50" for providing vacuum mechanical strength.

FIG. 19 shows modified showerhead plate 506 of the FIG. 15 embodiment. Modified showerhead assembly 506 is formed of a dielectric material such as aluminum nitride, aluminum oxide, boron nitrides or another suitable material and includes injector holes 516 and ICP coil segments 518. ICP coil segments 518 are bonded to the top portion of ICP showerhead plate 506 as six monolithic coil segments. Showerhead injector holes 516 include six rings of holes, each hole with a diameter in the range of 0.02 inches to 0.06 inches, with a total number of holes for each injector zone 1 through 6 ranging from 50 to 500 (outer rings to have more holes). Center hole 534 has a diameter of between 0.25 inches and 1.0 inches for passage of optical plug 110. ICP coil segments 518 fit within grooves 536 of modified showerhead 506 which have a depth of 0.001 to 0.1 inches and a width of 0.25 to 0.5 inches.

FIG. 20 shows the top surface view of modified showerhead plate 506. Modified showerhead 506 includes, in the FIG. 20 embodiment, six monolithic coil segments 518 that fill substrate grooves 536 (see FIG. 19) and include terminals 538 and 540 for external RF connections to external RF capacitor circuits. The showerhead 506 embodiment that FIG. 20 shows includes injector holes 516 for injecting processed gas into the process chamber for plasma processing of various substrates.

Bottom dielectric plate 506 serves two purposes. One is to provide multi-zone process gas injection, the other is to house coil segments 518 (formed by preformed metal segments to be sandwiched between the two dielectric plates or formed by sputtering and/or plating on dielectric plate 506) which are made of a suitable material such as aluminum or copper. Coil segments 518 fill shallow grooves (0.001" to 0.100") shaped as broken rings. The surface of dielectric plate 506 may be planarized using a mechanical polishing process, for example after filling the shallow trenches with metal.

FIG. 21 shows a bottom surface view of top dielectric plate 504 of the FIG. 15 embodiment. Attaching to top dielectric plate 504 are stainless steel tubes 512 for providing plasma process gas to gas dispersion cavities 514. Stainless steel tubes 512 are bonded stainless steel tubes for multi-zone gas injection through gas dispersion cavities 516, with two tubes positioned 180° apart for each gas dispersion cavity ring. Bonded aluminum rods 520 form six pairs for electrically connecting coil segments 518 to external RF capacitors and RF power supplies. FIG. 21 also shows opening 534 for passage of optical plug 110. Compared to the previous multi-zone ICP source embodiments of this invention, this last design offers some advantages due to its simplified structure and reduced fabrication cost.

Gas dispersion cavities 514 are formed as ring-shaped cavities (0.25"–0.50" wide by 0.25" to 0.50" deep). These cavities will overlay the multi-zone injector holes 516 in the bottom dielectric plate. Also shown in FIG. 21 are the gas inlet tube ends 520 (twelve tubes shown for a six-zone injector) located within the gas dispersion cavities. Each pair of inlet tubes are connected together externally to a single gas control manifold and valve to form a controlled six-zone (or n-zone with n=1,2,3, . . .) process gas injector.

Materials that work well to form dielectric plate 504 and modified showerhead 506 are numerous. However, certain materials are particularly preferred for the present embodiment. These materials include boron nitride, aluminum nitride and aluminum oxide. The reasons why these materials (e.g., AlN and BN) are preferable are discussed briefly to explain their advantages.

Boron nitride (BN)is highly refractory material with physical and chemical properties similar to carbon. Graphite-like (g-BN), wurzite (w-BN) and zinc blend (z-BN) are known polymorphs of BN corresponding to the graphite (hexagonal) and diamond (cubic) structures. Transformation of g-BN to w-BN occurs at pressures above 12 GPa at relatively low temperature (230° C.). Transformation of w-BN to z-BN occurs above 1300° C. and pressures above 5.5 GPa. Zinc blend (z-BN) is stable above 5.5 GPa and from 1100° to 1500° C.

All forms of BN are good electrical insulators, possessing band gaps of several electron volts (eV); electrical resistance of the hexagonal from varies from 1.7×10^{13} ohm-cm at 25° C. to 3×10^{4} ohm-cm at 1000° C. and is little affected by frequency. The dielectric constant of hexagonal BN is 3 with the electric vector parallel to the oasal plane and 5 perpendicular to the plane. Consistent with the short interatomic distances and light atomic weights, all forms of BN are very good thermal conductors. Boron nitride is chemically inert in most environments, resisting attack by mineral acids or wetting by glasses, slags and molten oxides, cryolite and fused salts, and most molten metals including aluminum. Its rate of oxidation in air is negligible below 1100° C.

Hexagonal boron nitride is commonly synthesized as a fine powder. Powders will vary in crystal size, agglomerate size, purity (including percent residual B_2O_3) and density. BN powders can be used as mold release agents, high temperature lubricants, and additives in oils, rubbers and epoxies to improve thermal conductance of dielectric compounds. Powders also are used in metal- and ceramic-matrix composites to improve thermal shock and modify wetting characteristics.

Hexagonal boron nitride may be hot pressed into soft (Mohs 2) and easily machinable, white or ivory billets having densities 90–95% of theoretical value (2.25 g/cm^3). Thermal conductivities of 17–58 W/m-K and CTEs of 0.4–5×10^{-6}/° C. are obtained, depending on density, orientation with respect to pressing direction and amount of boric oxide binder phase. Because of its porosity and relatively low elastic modulus (50–75 GPa), hot pressed boron nitride has outstanding thermal shock resistance and fair toughness. Pyrolytic boron nitride, produced by chemical vapor deposition on heated substrates, also is hexagonal; the process is used to produce coatings and shapes having thin cross sections.

Cubic boron nitride is second in hardness only to diamond. It is used for high-performance tool bits and in special grinding applications. Cubic BN tooling typically outlasts alumina and carbide tooling and is preferred in applications where diamond is not appropriate, such as grinding of ferrous metals. Aluminum Nitride (AlN) has a molecular weight of 40.99, density of 3.26 g/cm^3, CTE of 4.6×10^{-6}/° C., m.p. of 2200° C. under 4 atm of N_2, and sublimes at 1 atm. AlN has a white, hexagonal crystal structure and its powder hydrolyses on contact with water or water vapor. Water-resistant powders that allow aqueous processing are commercially available. AlN is stable against acids and only slightly reacts with bases. It is made by reacting aluminum metal with nitrogen, by reduction of aluminum oxide with

carbon in the presence of nitrogen or ammonia, or by decomposition of the product of reaction between aluminum trichloride and ammonia. AlN powder may be sintered to full density above 1800° C. in 1 atm of N_2 with the addition of sintering aids such as Y_2O_3 or CaO. Thermal conductivity in excess of 200 W/mK can be achieved in sintered parts, which is five times that of aluminum oxide. The dielectric strength of AlN is 1.5 times that of aluminum oxide, and electrical resistivity and mechanical strength are comparable to that of aluminum oxide. Its dielectric constant is about half that of aluminum oxide. Major applications include thermally conductive substrates and heat sinks for semiconductors, automotive and transit power modules, mobile communications and multichip modules. Other properties of AlN appear in the following table.

Properties of Aluminum Nitride

	Units	AlN
Volume resistivity	ohm-cm	$\geqq 10^{14}$
Dielectric constant	RT-1MHz	8.6
Dielectric loss	RT-1MHz	0.0005
Thermal conductivity	W/mK	170
Temperature coeff. of expansion RT-400° C.	10^{-6}/° C.	4.7
Density	g/cm^3	3.3
Hardness (Knoop)	GPa	11.8
Bending strength	MPa	276
Youngs modulus	GPa	331
Poisson ratio		0.25
Fracture toughness via chevron notch shorbar technique	MPa$\sqrt{m}$	3.44

FIG. 22 demonstrates the schematic diagram of a plasma equipment process chamber 600 comprising one of the multi-zone ICP structures of this invention. The particular example shown in FIG. 22 shows a three-zone configuration in conjunction with three RF power supplies for the ICP source structure. The multi-zone ICP source structure 601 employs a hermetically bonded structure of dielectric plates (e.g., made of a ceramic material with relatively high thermal conductivity) containing the ICP antenna coils and gas showerhead dispersion cavities (not shown). The ICP housing 601 is also hermetically bonded and sealed to the metallic vacuum plate or flange 603. The vacuum plate or flange 603 is placed onto the plasma equipment process chamber 605 and established chamber vacuum using vacuum seal 622. This configuration places the multi-zone ICP housing on the vacuum side 620 of the process chamber 605. The ICP source 601 provides a vacuum-sealed optical (e.g., sapphire or quartz) plug or viewport 604 for real-time in-situ process monitoring and control purposes by monitoring the plasma process side 620 and/or substrate 607 state parameters. For instance, FIG. 22 shows a full wafer interferometry sensor 617 mounted on top of the optical plug 604 for real-time in-situ monitoring and control of the plasma process uniformity on the substrate 607. Other in-situ sensors such as plasma emission sensors and spatially resolved plasma emission sensors may also be used for process monitoring and control purposes.

The multi-zone ICP source 601 is positioned over a chuck 606 supporting the substrate 607 to be processed. Preferably, chuck 606 controls the substrate 607 temperature by controlled heating and/or cooling during the plasma process. The substrate 607 is preferably clamped to the temperature-controlled chuck 606 either by electrostatic or mechanical means. Moreover, the chuck 606 preferably has a capability for up/down movement and height adjustment with respect to the ICP source housing 601. This will provide a very useful capability for adjusting the ICP source to substrate spacing in order to optimize the plasma process parameters such as process uniformity while maintaining sufficient process throughput. For instance, reducing the ICP source to substrate spacing results in increased plasma density and ion current density at the wafer, causing enhanced plasma process rate. If the ICP source to substrate spacing becomes too small, the process uniformity may degrade and there may also be additional problems associated with plasma-induced device damage and excessive eddy-current heating of the substrate 607.

The plasma process chamber provides a vacuum chamber access valve for automated loading and unloading of the substrate 607 into and out of the vacuum process chamber 605. Moreover, the plasma process chamber 605 connects to a vacuum pump (e.g., turbo pump and/or mechanical pump) via pump port 629.

The chuck 606 preferably provides an option for electrical biasing (e.g., 13.56 MHZ RF or 100 kHz–400 KHz AC power supply) of the substrate 607 via power supply 614 and coupling capacitor 615. This electrical bias provides a good control over the plasma ion energy impacting the substrate 607.

FIG. 22 shows a three-zone ICP configuration with the outer zone, middle zone, and inner zone powered by the RF power supplies RF_1 (608), RF_2 (609), and RF_3 (610), respectively. As shown in this FIGURE, the RF power supplies are connected to the ICP antenna zones, preferably via series blocking capacitors 630, 631, and 632. Moreover, external inter-segment series capacitors C_1 (611), C_2 (612), and C_3 (613) connect the antenna segments in series within each zone (outer zone, middle zone, and inner zone, respectively). These series capacitors ensure reduced induced RF voltages within various zones, resulting in improved inductive plasma coupling and reduced parasitic capacitive coupling of the energy source to the plasma medium. The multi-zone ICP 601 RF power supplies (608, 609, 610) may employ source frequencies over a wide range (e.g., 1 MHZ to over 30 MHZ), and preferably a fixed 13.56 MHZ frequency. Moreover, these multi-zone power supplies may use external RF matching networks (not shown in FIG. 22) placed between the RF power supplies and the ICP antenna zones for improved load matching, improved RF power coupling, and improved plasma process repeatability. The RF power supplies may also employ phase shifters 616 in order to control the phase angles among various RF power supplies for improved process uniformity and repeatability.

The phase shifters 616 become non-essential when the power supplies use different frequencies. For instance, if a 100 kHz power supply is used for the substrate bias and three 13.56 MHZ RF power supplies are employed for powering the multi-zone ICP antenna, there is no need for a phase shifter between the substrate power supply and the multi-zone ICP power supplies. The ICP RF power supplies,

however, may employ phase shifters/controllers to control the phase angles for RF_1 (608), RF_2 (609), and RF_3 (610).

FIG. 22 also shows the coolant inlet 633 and coolant outlet 634 lines for flowing the coolant (e.g., cooling water) through the metallic vacuum lid. Due to the hermetically sealed bonded structure of the ICP source with the thermally conductive bonded/sealed interfaces 640 (between the top dielectric plate and the metallic vacuum lid) and 641 (between the lower and upper dielectric or ceramic plates), the cooled metallic vacuum plate/lid also serves as an effective heat removal or heat sink medium for the ICP housing. This will ensure that the ICP housing temperature with maximum RF power levels running through the antenna segments will remain well below 100° C.

As shown in FIG. 22, the ICP process gases 635 are fed to the ICP showerhead plate 602 via the gas manifolds 618 and 619. The external manifolding of the ICP gas lines can be designed to meet the specific plasma process uniformity and defect density requirements. The gas injection system can be set up for either single-zone or multi-zone gas injection (a two-zone injection using two gas manifolds is shown in FIG. 22).

FIG. 23 shows an example of a two-manifold gas injection configuration 700 used with the multi-zone ICP source structures of this invention. FIG. 23 shows six pairs of gas inlet lines 703 for the multi-zone ICP source. The schematic diagram of FIG. 23 also shows up to six different process gases 704 and 705 coming from the ICP equipment gas box. The multi-zone ICP source dispersion cavities employ one pair of inlets for each gas dispersion cavity corresponding to each gas injection ring of holes in the showerhead. For instance, SH-61 and SH-62 both connect to the sixth (or outermost) gas dispersion cavity in the multi-zone ICP source structure while the inlet lines SH-11 and SH-12 both connect to the first (or innermost) gas dispersion cavity. As shown in the example of FIG. 23, process gases A, B and C (705) are connected together via the first gas manifold 701 and subsequently inject into the showerhead injection rings 2, 4, and 6. On the other hand, process gases D, E, and F (704) are connected together using the second gas manifold 702 and subsequently inject into the plasma process chamber via the showerhead injection rings 1, 3 and 5 (SH-11/SH-12, SH-31/SH-32, and SH-51/SH-52 inlets). This arrangement effectively configures the multi-zone ICP injector as a two-zone showerhead where premixing of the first group of process gases 705 and the second group of process gases 704 is prevented. It should be understood that other gas connection configurations and zone partitioning arrangements are possible for the multi-zone ICP structures of this invention.

FIGS. 24A and 24B illustrate a three-zone and a two-zone ICP mixing arrangement, respectively, for one embodiment of this invention with six antenna segments. As shown in FIG. 24A, an RF power supply 801 is used to provide substrate bias via series or blocking capacitor 814. Moreover, the ICP antenna segments (six segments in this example) are externally partitioned and wired to form three ICP zones (edge zone 811, middle zone 812, and center zone 813). In edge zone 811, the outer two antenna segments (segments 1 and 2 with connector nodes C_{11}/C_{12} and C_{21}/C_{22}) employ a series capacitor 808 to bridge the two segments. A first RF_1 power supply 803 connects to C_{11} and C_{22} via series blocking capacitor 815. The middle zone 812 is formed by bridging the third and fourth antenna segments using a series capacitor 809 placed between nodes C_{32} and C_{41}. A second RF_2 power supply 805 powers the middle zone 812 via series blocking capacitor 816. Inner zone 813 is configured by combining the fifth and sixth antenna segments using a series capacitor 810 placed between nodes C_{52} and C_{61}. A third RF_3 power supply 807 powers the inner zone via series blocking capacitor 817. Three phase shifters/controllers 802, 804, 806 may be used in order to control the relative phase angles of various RF power supplies for process uniformity and repeatability. For a given multi-zone ICP source structure, various types of ICP antenna segment partitioning may be used for a given number of zones. In the example shown in FIG. 24A, each antenna zone has received two adjacent antenna segments. The optimum partitioning configuration should provide the best amount of control over plasma process uniformity.

FIG. 24B illustrates a two-zone ICP arrangement wherein the outer zone is formed by grouping the first and second antenna segments while the inner zone is configured by grouping the third through sixth antenna segments. The outer zone employs a series capacitor between nodes C_{12} and C_{21} in conjunction with a first RF_1 power supply 905 connected to nodes C_{11} and C_{22} via a series blocking capacitor 913. The inner zone utilizes series capacitors 908 (between nodes C_{32} and C_{41}), 909 (between nodes C_{42} and C_{51}) and 910 (between nodes C_{52} and C_{61}). A second RF_2 power supply 906 connects to inner zone nodes C_{31} and C_{62} via series blocking capacitor 914. An RF power supply 901 connects to the plasma equipment chuck via series blocking capacitor 902 in order to produce substrate RF bias. Phase shifters/controllers 903 and 904 may be used in order to control the relative phase angles of various RF power supplies.

One important advantage of the multi-zone ICP structures and methods of this invention is that for any given source structure numerous multi-zone wiring arrangements and antenna segment partitioning configurations are possible simply by changing the electrical wiring external to the source. Therefore, this invention provides a significant amount of flexibility for optimizing the multi-zone ICP source zoning and partitioning in order to establish the widest possible plasma process window and the best process uniformity. Moreover, the multi-zone ICP source structures and methods of this invention are scalable to allow uniform processing of larger substrates such as 300-mm silicon wafers and large-area flat-panel display substrates.

The hermetic sealing fabrication method preferably used for fabrication of the multi-zone ICP source structures of this invention result in extremely high vacuum integrity, ultra-high vacuum (UHV) compatibility, and ultra-clean plasma processing. For instance, the multi-zone ICP source structures of this invention are compatible with vacuum base pressures as low as 5×10^{-9} Torr and better.

For a given multi-zone ICP source structure and a specified process application, the optimum zoning and antenna segment partitioning (or grouping) between the antenna zones can be obtained by performing a series of Design-of-Experiments (DOE) with various external wiring configurations. The multi-zone ICP series capacitors are selected to minimize the antenna RF voltages within various zones depending on the RF frequency.

In most practical plasma process applications, the multi-zone ICP structures of this invention can meet the process requirements using a two-zone or a three-zone configuration (e.g., two-zone configuration for up to 200-mm wafer processing). Larger substrates (e.g., 300-mm silicon wafers) may benefit from a higher number of zones. A multi-variable real-time controller may be used in conjunction with a suitable sensor (e.g., a full-wafer interferometry sensor) in order to control the process uniformity and repeatability.

The multi-zone ICP structures of this invention may employ either straight lined-up electrical connection feedthroughs for the ICP antenna segments (as described and shown for various embodiments) or they may utilize staggered electrical feedthroughs in order to prevent any possible plasma process non-uniformities associated with the lined up segment ring breaks in a non-staggered arrangement. For instance, for a multi-zone ICP structure with eight circular antenna segments, one type of design may employ eight pairs of electrical feedthrough connector leads lined up along two straight (nearly radial) lines extending between the center and edge regions of the ICP housing. In this design, there may be some plasma density non-uniformity directly underneath the source (and very close to the source) and between the two segment feedthrough lines. This possible non-uniformity can be produced due to the break in the current flow through each broken antenna segment ring and due to the cumulative non-uniformity effects of the non-staggered or straight lined-up feedthroughs. On the other hand, the eight pairs of feedthroughs for eight broken ring antenna segments can be staggered at, for instance, 40° to 45° for each pair of adjacent segments in order to utilize the full 360° planar staggering of the feedthroughs in a spiral pattern. This will eliminate the possible cumulative non-uniformity effects of various antenna segment breaks and associated feedthroughs. Thus, the minimum allowable ICP source-to-substrate spacing for acceptable plasma process uniformity is smaller in the case of staggered electrical feedthroughs (e.g., spiral staggered feedthrough pattern) compared to the non-staggered feedthrough pattern.

Due to the proximity of the gas dispersion cavities to the multi-zone antenna segments in various TCP embodiments of this invention, there is a possibility of plasma formation within the gas dispersion cavities. This possible plasma formation in the gas dispersion cavities can be avoided by various means and techniques. One method is to fill the gas dispersion cavities with a suitable ceramic fiber or ceramic powder (e.g., with controlled spherical ceramic particle size). Filling the gas dispersion cavities with a ceramic powder or a ceramic filler can be performed prior to final assembly and hermetic bonding of the multi-zone ICP source structure.

The multi-zone ICP source structures of the present invention may use separate RF power supplies and dedicated matching networks for each of the ICP antenna zones (e.g., three RF power supplies and three RF matching networks for a 3-zone ICP source wiring arrangement). Another method, however, is to electrically wire the zones in parallel with either a fixed capacitor or a variable capacitor connected in series with each of the zones in order to adjust the effective load impedance and electrical current associated with each zone. Another possibility is to use adjustable (e.g., mechanically adjustable with server or stepper motors) transformer couplings for various zones with a single transformer primary coil attached to a single RF power supply and a single RF matching network (RF matching network may not be needed). These possible arrangements allow effective real-time multi-zone ICP plasma uniformity control with a single RF power supply, resulting in reduced system cost and complexity. FIGS. 25A and 25B show examples of two power supply wiring arrangements enabling 3-zone ICP operation and control using a single RF power supply. FIG. 25A shows a parallel capacitive wiring arrangement while FIG. 25B demonstrates an adjustable transformer coupling configuration allowing multi-zone operation. A real-time multi-variable controller will provide control signals for the stepper or servo motors controlling the variable capacitor valves or the extent of transformer coupling ratios. For instance, a multi-variable real-time controller will adjust the multi-zone transformer coupling ratios M_1, M_2, and M_3 for real-time multi-zone uniformity control.

The present invention also proposes a hermetic sealing fabrication process for construction of various planar single-zone and multi-zone source structures for various plasma processing applications. The hermetic sealing fabrication process of this invention eliminates the need for elastomer-ring seals for the ICP source assembly, resulting in improved vacuum integrity (i.e., reduced plasma chamber vacuum base pressure and reduced leak-back rate), improved process cleanliness, and increased source lifetime. Polymer-based vacuum seals such as elastomer O-ring seals tend to degrade over time particularly in presence of plasma and/or heat.

The preferred fabrication method of this invention employs a thermal bonding or brazing process for final assembly of the source structure. For instance, the preferred fabrication method of this invention is briefly described for the fourth multi-zone source structure of this invention employing a metallic vacuum plate or vacuum lid and two dielectric plates. As shown in FIG. 26, ICP source structure **1000** comprises vacuum lid/plate **1010**, upper dielectric plate **1030**, and lower dielectric plate **1050**. Vacuum lid/plate **1010** can support the entire ICP housing, provide the process gas inlets and electrical feedthroughs (not shown here), and serve as a cooling medium for the ICP source housing during operation. Upper dielectric plate **1030** is preferably made of a high thermal conductivity ceramic material such as aluminum nitride (AlN) which provides a medium for hermetic sealing of various process gas inlets and electrical feedthroughs. Upper dielectric plate **1010** serves to separate the ICP antenna structure from the metallic (e.g., stainless steel) cooled base plate **1010** for effective inductive RF coupling to the plasma medium, to contain the gas dispersion cavities, and as a heat transfer medium for effective cooling of the ICP antenna structure (located at the bottom of this upper dielectric plate **1030**) during the ICP source operation. Lower dielectric plate **1050** preferably holds the ICP antenna structure and the gas injection holes that communicate with the gas dispersion cavities in the upper dielectric plate **1030**. Lower dielectric plate **1050** is also preferably made of a high thermal conductivity ceramic material such as AlN.

A preferred ICP source fabrication process flow is now described. Referring to FIG. 26, the metallic vacuum plate/lid **1010** is separately manufactured using a suitable material such as stainless steel (or aluminum). Preferably, stainless steel is used for fabrication of vacuum plate **1010** for ultra-high vacuum (UHV) applications requiring extremely low vacuum base pressures. Vacuum plate **1010** holds the embedded coolant channels for running a coolant (e.g., water) flow as well as various through holes for passage of the metallic rods connecting to the antenna segments as well as the process gas inlet tubes. The bottom surface of vacuum plate **1010** is highly polished in order to provide a suitable area for a subsequent hermetic bonding or brazing process. The lower or bottom surface of the stainless steel vacuum lid/plate **1010** (corresponding to the ICP housing area) is then coated with a suitable thermal bonding or brazing material (e.g., tin, indium or a suitable alloy) by sputtering or electroplating.

The upper dielectric (e.g., AlN or ceramic) plate **1030** is also separately fabricated along with various embedded gas dispersion channels positioned on its bottom surface as well as all the necessary through holes for tight (e.g., shrink fit)

insertion of the process gas feed lines and the antenna connector rods. For instance, for a multi-zone ICP source with six antenna segments and six gas dispersion cavities, upper dielectric plate **1030** may contain twelve holes for tight fit insertion of six pairs of electrical connector rods and another six pairs of holes for tight fit insertion of six pairs of stainless steel gas inlet tubes. For instance, if the electrical connector rods and gas inlet tubes all have 0.25 inch external diameters, the lower dielectric plate **1050** should have twenty-four through holes with each through hole having a diameter of 0.25 inch. The inner sidewalls of the through holes, the top surface, and select areas on the bottom surface of the upper dielectric plate **1030** are coated with a suitable hermetic thermal bonding material such as indium, tin, or a suitable metallic alloy with a relatively low (e.g., ≦400° C.) melting point. This coating process may be performed by plasma sputtering, evaporation, or electroplating.

Similarly, the external surfaces of the electrical connector rods and gas line tube sections are also coated with the same thermal bonding or brazing material (e.g., indium, tin, or a suitable metallic alloy) using a suitable material deposition process (plasma sputtering, vaporization, electroplating, or other process). Subsequently, the electrical connector rods and gas inlet tube sections are cooled (e.g., in liquid nitrogen) and rapidly inserted into the respective through holes fabricated in the upper dielectric plate **1030**.

Separately, the lower dielectric plate **1050** is fabricated along with the shallow trenches on its top surface for insertion of antenna segment broken rings and through gas injection holes. The broken ring antenna segments may be formed by filling the shallow trenches with a suitable metal such as aluminum or copper using one or a combination of physical-vapor deposition (e.g., plasma sputtering) and electroplating processes. An alternative method is to separately form the individual antenna segments (e.g., by machining or stamping) and subsequently insert them in their respective trenches on the lower dielectric plate **1050** to be permanently sandwiched between the two dielectric plates **1030** and **1050** during the final assembly. Select areas of the top surface of the lower dielectric plate **1050** (for instance, continuous narrow rings, one near the edge of the ICP dielectric housing, and additional narrow rings located between the adjacent antenna segments and not overlapping with the positions of the gas dispersion cavities in the upper dielectric plate **1030** after the final assembly) are also coated with the thermal bonding or brazing material (indium, tin, or a suitable metallic alloy).

Subsequently, the ICP source assembly comprising the metallic vacuum plate **1010**, upper dielectric plate **1030** with all associated electrical rods and gas tubes, and the lower dielectric plate **1050** along with the ICP antenna segments placed in the designated shallow trenches, is assembled and temporarily held together by mechanical clamping of the assembled structure. Assembling the ICP source is performed by first bringing the metallic vacuum plate **1010** and top dielectric plate **1030** together and feeding the ends of the electrical rods and gas tube lines tightly attached to the upper dielectric plate **1030** through the respective larger diameter through holes formed in the vacuum plate **1010**. This will allow the bottom surface of the vacuum plate **1010** to come into a clean planar contact with the top surface of the upper dielectric plate **1030**. Both these surfaces are covered with the bonding material (indium, tin, or another material) through the entire interface contact region **1020** shown between points A and B in the cross-sectional view of FIG. **26** (for simplicity, FIG. **26** does not show structural details such as the rods or tubes). Then, the lower dielectric plate **1050** is brought into contact with the upper dielectric plate **1030**, sandwiching the antenna segments (not shown in FIG. 26) between them.

FIG. **26** also shows a cross-sectional view of the circular rings of the bonding material coating layers **1040** (shown as multiple lines between points C and D) on the bottom surface of upper dielectric plate **1030** and on the top surface of lower dielectric plate **1050** (the top and bottom coating patterns are mirror images of each other).

After mechanical clamping of the entire structure, the mechanically clamped assembly is placed inside a vacuum or purged thermal furnace and heated to an appropriate temperature (e.g., up to 200° 0 300° C. for indium or tin bonding) and then cooled down and removed. This will result in thermal fusing of the assembled structure by formation of hermetically sealed bonded junctions wherever the bonding material coatings have been in contact. For instance, hermetically sealed bonded junctions are formed as bonded interface region **1020** between the ICP housing top dielectric plate **1030** and metallic vacuum plate/lid **1010**, as well as in the continuous rings **1040** at the interface between the upper dielectric plate **1030** and lower dielectric plate **1050**. Moreover, this thermal anneal process will form hermetically sealed junctions between the electrical rods and their respective support holes as well as between the gas inlet tubes and their respective support holes in the upper dielectric plate **1030**. The temporary mechanical clamping device can then be removed. This process will result in a fully hermetically-sealed and self-supporting ICP source structure without any need for elastomer seals and without any need for permanent clamping brackets or screens. This hermetically-sealed ICP source can then be mounted on a plasma equipment process chamber using a conflat flange metal seal between the vacuum lid **1010** and the process chamber for vacuum integrity and process cleanliness.

The key advantages of the hermetic sealing fabrication process flow of this invention can be summarized as follows:

- No elastomer seals resulting in improved process cleanliness, enhanced vacuum integrity, and improved source lifetime.
- Hermetically sealed bonded junctions provide low-thermal resistance heat transfer junctions, allowing cooling of the ICP housing by the cooled vacuum plate **1010**.
- Hermetically sealed structure eliminates the possibility of any outgassing and/or virtual leak surfaces/junction resulting in improved vacuum integrity and process cleanliness.
- Hermetical sealing fabrication process flow is applicable to various single-zone and multi-zone planar ICP designs of this invention and prior art structures.
- The hermetical sealing fabrication process flow results in reduced cost-of-ownership for ICP-based plasma processing while enabling high-performance plasma processing. This is due to extended ICP source reliability, lifetime, and enhanced process cleanliness.

Although the invention has been described in detail herein with reference to the illustrative embodiments, it is to be understood that this description is by way of example only and is not to be construed in a limiting sense. It is to be further understood, therefore, that numerous changes in the details of the embodiments of the invention and additional embodiments of the invention, will be apparent to, and may be made by, persons of ordinary skill in the art having reference to this description. It is contemplated that all such changes and additional embodiments are within the spirit and true scope of the invention as claimed below.

What is claimed is:

1. A method of fabricating a hermetically-sealed ICP source structure, comprising:

forming a dielectric housing including an integral inductively-coupled source antenna;

forming a source support plate;

placing a bonding material between said dielectric housing and said source support plate;

mechanically clamping said dielectric housing against said support plate to form a structure having the bonding material between said dielectric housing and said support structure; and

performing a thermal anneal process on said clamped structure to form a hermetically-sealed junction between said dielectric housing over the entire area of said support plate.

2. The method of claim 1 wherein placing a bonding material between said dielectric housing and said source support plate further comprises placing a thin foil of thermal bonding material between said dielectric housing and said source support plate, said thin foil having a melting temperature T<600° C.

3. The method of claim 1 wherein placing a bonding material between said dielectric housing and said source support plate further comprises depositing a low melting point material layer on a surface of the said dielectric housing.

4. The method of claim 3 wherein depositing a low melting point material layer on a surface of said dielectric housing further comprises depositing a layer of indium on a surface of said dielectric housing.

5. The method of claim 3 wherein depositing a low melting point material layer on a surface of said dielectric housing further comprises sputtering a low melting point material layer on a surface of said dielectric housing.

6. The method of claim 3 wherein depositing a low melting point material layer on a surface of said dielectric housing further comprises electroplating a low melting point material layer on a surface of said dielectric housing.

7. The method of claim 3 wherein depositing a low melting point material layer on a surface of said dielectric housing further comprises evaporating a low melting point material layer on a surface of said dielectric housing.

8. The method of claim 1 wherein forming a dielectric housing further comprises;

forming a lower dielectric plate;

forming an Upper dielectric plate; and coupling said lower dielectric plate to said upper dielectric plate such that an inductively-coupled source antenna is held between said lower dielectric plate and said upper dielectric plate.

9. The method of claim 8 wherein forming a lower dielectric plate further comprises;

forming the lower dielectric plate from ceramic material with a relatively high thermal conductivity;

forming a plurality of shallow trenches on a surface of said lower dielectric plate facing said upper dielectric plate; and

forming a plurality of gas injection holes operable to allow passage of a plurality of electrical connector rods and a plurality of process gas inlet tubes.

10. The method of claim 9 wherein forming an upper dielectric plate further comprises;

forming the upper dielectric plate from ceramic material with a relatively high thermal conductivity;

embedding a plurality of gas dispersion channels on a surface of said upper dielectric plate facing said lower dielectric plate; and

forming a plurality of through holes on a surface opposite the plurality of gas dispersion channels for

receiving a plurality of process gas inlet tubes and a plurality of electrical connector rods.

11. The method of claim 10 wherein forming a support plate further comprises;

forming the support plate from a metallic material;

forming the support plate to have a highly polished surface on a side operable to receive a bonding material for coupling said support plate to said dielectric housing;

forming a plurality of cooling channels in the support plate, said coolant channels operable to flow a coolant to cool said ICP source; and

forming a plurality of through holes in the support plate operable to allow passage of a plurality of electrical connector rods and a plurality of process gas inlet tubes.

12. The method of claim 11 further comprising;

coating the highly polished surface of the support plate with a bonding material;

coating the feedthrough hole sidewalls of the upper dielectric plate and the upper dielectric plate with a bonding material;

coating the surface of the upper dielectric plate facing the support plate with a bonding material;

coating selected portions of the upper dielectric plate facing the lower dielectric plate with a bonding material;

coating the external surfaces of the plurality of electrical connector rods with a bonding material;

coating the external surfaces of the plurality of process gas inlet tubes with a bonding material;

inserting said plurality of process gas tubes and electrical connection rods through said support plate; cooling said plurality of process gas tubes and electrical connection rods;

inserting the cooled process gas tubes and electrical connection rods into the respective through holes in said upper dielectric plate;

inserting a plurality of antenna segments into the shallow trenches formed in the lower dielectric plate;

coating the surface of the lower dielectric plate facing the upper dielectric plate with a bonding material;

assembling said support plate, said upper dielectric plate, and said lower dielectric plate.

13. The method of claim 12 wherein assembling said support plate, said upper dielectric plate and said lower dielectric plate further comprises;

feeding said plurality of electrical connector rods and said plurality of process gas inlet tubes through the respective through holes formed in said support plate;

bringing said polished support plate surface with bonding material in contact with said upper dielectric plate surface facing said support plate;

bringing said shallow trench surface of lower dielectric plate having the bonding material in contact with said upper dielectric plate surface facing said lower dielectric surface;

clamping the entire support plate, upper dielectric plate, and lower dielectric plate structure together; and

heating the clamped structure to an appropriate bonding temperature and subsequently cooling the clamped structure to thermally fuse the surfaces with a bonding material to form a hermetically sealed bonded junctions at these surfaces.

14. The method of claim 8 wherein coupling said lower dielectric plate to said upper dielectric plate further comprises thermally bonding said lower dielectric plate to said upper dielectric plate to form a hermetically-sealed contact junction between said lower dielectric plate and said upper dielectric plate.

15. The method of claim 14 wherein thermally bonding said lower dielectric plate to said upper dielectric plate further comprises thermal bonding a relatively low melting point alloy with melting temperature T<600° C. between said lower dielectric plate and said upper dielectric plate.

16. The method of claim 8 wherein coupling said lower dielectric plate to said upper dielectric plates further comprises thermally brazing said lower dielectric plate to said upper dielectric plate to form a hermetically-sealed contact junction between said lower dielectric plate and said upper dielectric plate.

17. The method of claim 11 wherein forming said support plate further comprises forming a stainless steel support plate.

18. The method of claim 11 wherein forming said support plate further comprises forming an aluminum support plate.

19. The method of claim 1 further comprising coupling said support plate to a plasma process chamber to provide a vacuum seal interface to the plasma process chamber.

20. The method of claim 1 further comprising:

forming a substantially planar dielectric housing;

forming a substantially planar source support plate; and

forming a substantially planar hermetically-sealed junction.

21. The method of claim 13 further comprising forming a monolithic source antenna by depositing an electrically conducting metallic layer onto the surface of the lower dielectric plate having shallow trenches.

22. The method of claim 1, wherein the hermetically-sealed function comprises a continuous hermetic interface between a surface of the dielectric housing in contact with a surface of the source support plate.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,203,620 B1
DATED : March 20, 2001
INVENTOR(S) : Mehrdad M. Moslehi

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Title page,
Item [73], Assignee, insert -- **CVC Products, Inc.** of Rochester, N.Y. --.

Signed and Sealed this

Tenth Day of September, 2002

Attest:

JAMES E. ROGAN
Director of the United States Patent and Trademark Office

Attesting Officer

United States Patent [19]

Mahler

[11] **Patent Number: 4,595,483**

[45] **Date of Patent: Jun. 17, 1986**

[54] **CATHODE SPUTTERING APPARATUS WITH ADJACENTLY ARRANGED STATIONS**

[75] Inventor: Peter Mahler, Hainburg, Fed. Rep. of Germany

[73] Assignee: **Leybold Hearaeus GmbH**, Cologne, Fed. Rep. of Germany

[21] Appl. No.: **716,854**

[22] Filed: **Mar. 28, 1985**

[30] **Foreign Application Priority Data**

Apr. 6, 1984 [DE] Fed. Rep. of Germany 3413001

[51] **Int. Cl.**[4] **C23C 15/00**

[52] **U.S. Cl.** .... **204/298**; 204/192 R

[58] **Field of Search** .... 204/298, 192 R

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Primary Examiner—Arthur P. Demers

Attorney, Agent, or Firm—Felfe & Lynch

[57] **ABSTRACT**

Cathode sputtering apparatus with at least two adjacently arranged stations including a charging station and a coating station. At least one sputtering cathode and a substrate carrier that can execute reciprocatory movement between the stations are arranged on a vacuum chamber. The substrate carrier is secured by means of an extension arm eccentrically on a pivot bearing passing through the vacuum chamber. A coolant circulation line is led through the pivot bearing to the substrate holder.

7 Claims, 5 Drawing Figures

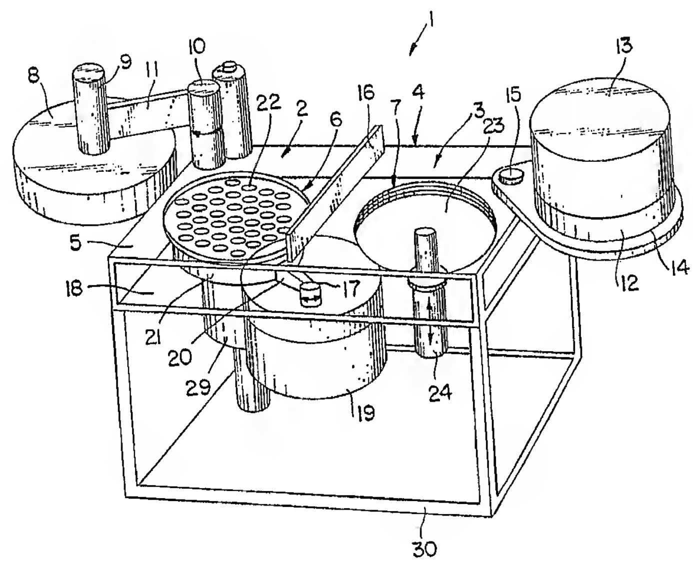


Exhibit E

FIG. 1

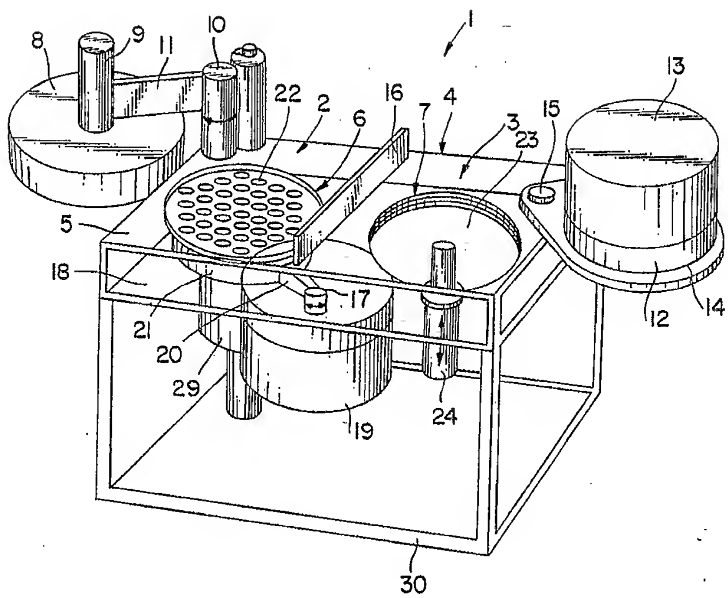


FIG. 2

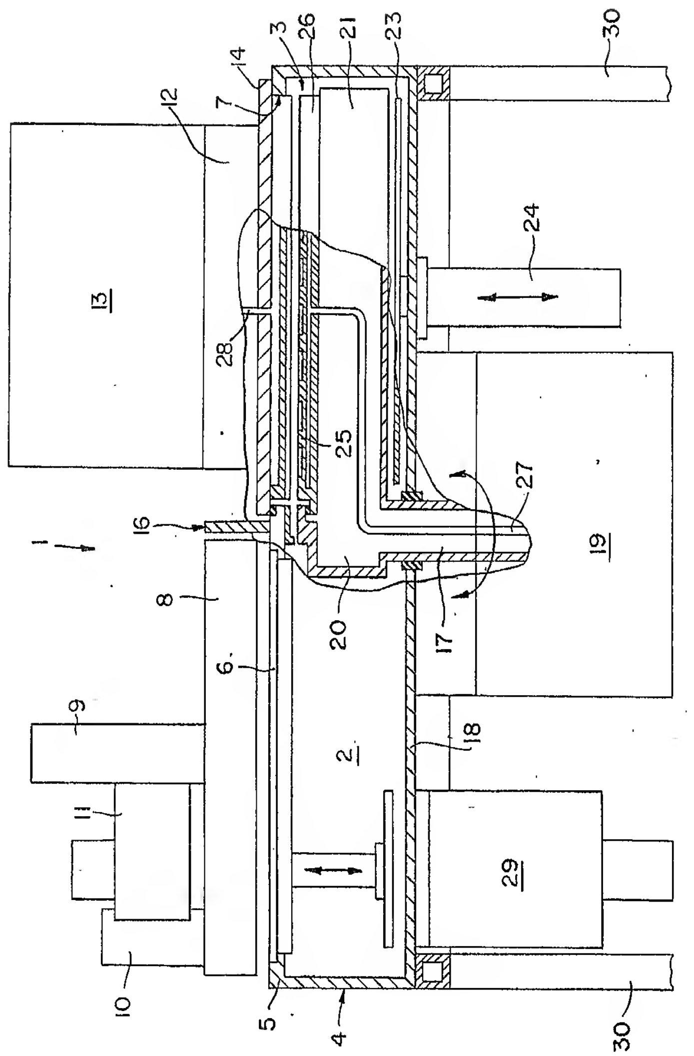
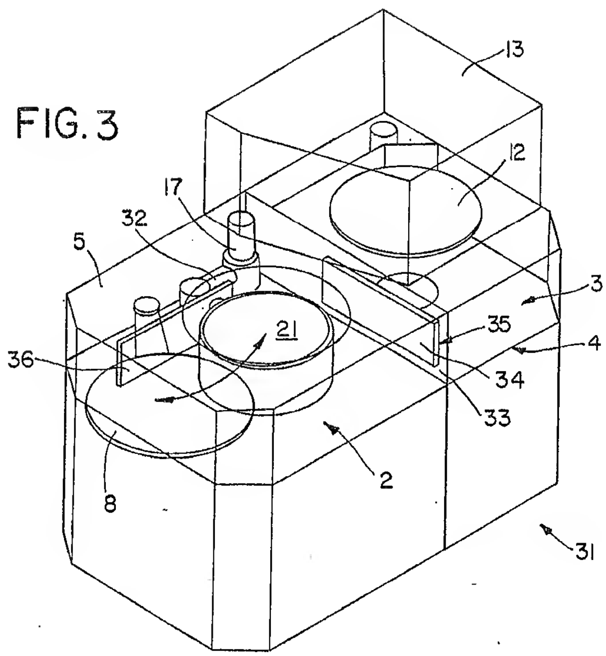


FIG. 3



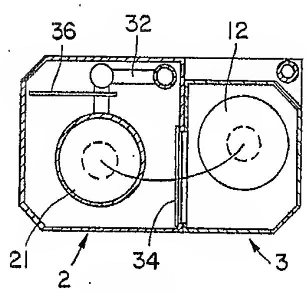


FIG. 4

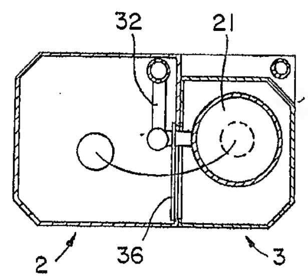


FIG. 5

CATHODE SPUTTERING APPARATUS WITH ADJACENTLY ARRANGED STATIONS

This invention relates to cathode sputtering apparatus with at least two adjacently arranged stations including a charging station and a coating station, and with a vacuum chamber, at least one sputtering cathode, and a substrate holder able to execute reciprocal movement between the stations.

With such a cathode sputtering unit the charging station may coincide with an etching station so that the unit overall consists of only two stations.

A cathode sputtering unit with three stations is known from German published patent application DE-OS No. 29 32 483, in which a corresponding number of substrate holders is arranged on a circular disc that can rotate about a concentric axis in the manner of a carousel. In this unit, however, no coolant circulation is provided for the individual substrate holders, with the result that it is practically impossible to maintain a specific temperature level during the individual treatment procedures. Furthermore, with such types of units it is practically impossible to avoid cross-contamination between the individual stations since it is not possible for structural reasons to install air-lock valves between the individual stations, In particular, it is also not possible, for example, to open the charging station and at the same time operate the adjacent coating station.

Cathode sputtering units composed of so-called module units also belong to the state of the art. In this case several stations are separated each by its own vacuum chamber, and a series arrangement of such vacuum chambers is sealed off with respect to the atmosphere by air-lock valves between the chambers as well as at both ends of the unit. A semi-continuous mode of operation is possible with such an arrangement, and also cross-contamination is prevented by the air-lock valves. The substrates are passed linearly through all the stations by means of plate-shaped substrate carriers mounted on rollers. However, it is difficult to cool the substrate sufficiently since it is not possible, for example on account of the air-lock valves, to maintain the movable substrate holders permanently connected up to a coolant circulation. With such units one has, therefore, had to resort to placing the substrate holders in the individual stations on stationary cooling plates. Such a method of cooling is, however, inadequate for certain heat-sensitive products, and in particular is virtually unreproducible.

As regards the question of substrate cooling, it may be mentioned that substrates that have to be kept very strictly at a specific temperature are bonded by means of a heat-conducting composition to the substrate holder so as to ensure a good heat transfer between these components. However, a very weak 'link' in the heat conduction chain is formed as a result of placing a movable substrate holder on stationary cooling plates provided with a coolant circulation, i.e. the heat transfer conditions between the substrate holder and the cooling are not reproducible, and the result is a relatively high temperature gradient. The interruption in the heat conduction due to a more or less narrow air gap is particularly critical if two treatment procedures that both involve a thermal loading or stress of the substrate directly follow one another in adjacent stations.

Thermal stress of the substrate is particularly unavoidable in so-called plasma processes that form the basis of a cathode sputtering procedure as well as a plasma etching procedure. In this connection, the thermal stress with so-called diode systems is greater on account of the longer duration of the procedure, than in so-called magnetron cathodes, in which the plasma discharge is limited to a narrow region of the cathode and target surfaces. The thermal stress is less simply on account of the substantially shorter coating time, in which the sputtering rate is greater by a factor of 10 to 30. However, for numerous processes in which a high layer uniformity is an important feature such magnetron cathodes cannot be used, or can be used only under complicated operating conditions, on account of the spatially and locally restricted sputtering procedure, so that in these cases too the so-called diode sputtering is used as before. A diode process is also involved in so-called plasma etching, in which the substrate holder together with the substrates is insulated with respect to the vacuum chamber and is connected to a high frequency generator. In this case the sputtering direction is reversed and the material to be stripped form the substrates by the etching process migrates in the direction of a collection plate in the etching station. This procedure too is associated with a high thermal stress of the substrate since the plasma discharge acts in this case directly on the substrate surface. In principle it is also possible to perform etching under the action of a magnetic field, though in practice the so-called diode processes predominate for reasons of uniformity.

An object of the invention is, therefore, to improve substantially a cathode sputtering apparatus so that the substrates can be constantly cooled under reproducible conditions during their path through the individual stations.

This objective is achieved in accordance with the invention by virtue of the fact that the substrate holder is secured by means of an extension arm eccentrically to a pivot bearing passing through the vacuum chamber, and that a coolant circulation is led through the pivot bearing to the substrate carriers.

By means of the measure according to the invention, the conventional linear movement of the substrate carrier in cathode sputtering units is replaced by a pivoting movement on a circular path around the pivot bearing, and the pivot bearing can be used to connect the substrate holder permanently to the coolant source. In this case it is possible to keep the substrate holder permanently cooled not only in all the stations but also during its path from one station to another station and thereby maintain the intimate thermal contact between the substrates and the substrate holder and coolant circulation, for example by means of a heat-conducting composition.

According to a further embodiment of the invention, it is particularly advantageous if the substrate holder is mounted in an insulated manner with respect to the vacuum chamber and is connected to a high frequency generator.

In such a case the charging station can be used in a particularly simple way as an etching station. By applying a high frequency to the substrate holder and by virtue of the surface ratio of the substrate holder to the opposite wall surfaces of the charging station, the latter effectively become the anode and the substrates can be etched by the resultant plasma process. In particular, the charging cover can assume the function of the

anode and serve as a suspension means for the etched material. To this end, the charging cover is preferably provided with a replaceable plate.

It is also particularly advantageous if the vacuum chamber is in the form of a parallelepiped and has two circular recesses in its upper chamber wall, one of which can be closed by the sputtering cathode and the other of which can be closed by the already described charging cover, and if the axis of the pivot bearing lies in a vertical plane of symmetry running between the recesses.

Such a measure enables the substrate holder in the charging station to be lightly coated from above by swinging the charging cover sideways. Parts of the unit are also readily accessible in the coating station after dismantling the sputtering cathode.

By means of the invention the substrates can also be kept permanently cooled in a particularly simple manner by separating the individual stations by means of a valve.

According to a further embodiment of the invention, this is achieved if a partition with a valve seat and a first valve closure is arranged between the two stations, and if the extension arm has a second valve closure that can be brought into position on the valve seat by swinging the substrate carrier into the coating station.

In this case the substrate carrier additionally has the function of a valve, it being assumed of course that the first valve closure is moved into a position that does not hinder the second valve closure. The coolant circulation can thus be maintained in an uninterrupted manner, and cross-contamination between the individual treatment stations is absolutely avoided.

In accordance with the invention, cathode sputtering apparatus comprises a vacuum chamber and at least two adjacently arranged stations including a charging station and a coating station. The apparatus also includes at least one sputtering cathode means, a substrate holder able to execute reciprocal movement between the stations, and a pivot bearing passing through the vacuum chamber. The apparatus also includes an extension arm on the pivot bearing. The substrate holder is secured by means of the extension arm eccentrically on the pivot bearing. The apparatus also includes coolant circulation means led through the pivot bearing to the substrate holder.

For a better understanding of the invention, together with other and further objects thereof, reference is made to the following description, taken in connection with the accompanying drawings, and its scope will be pointed out in the appended claims.

Referring now to the drawings:

FIG. 1 is a perspective view of cathode sputtering apparatus with two stations, showing both the charging cover and the sputtering cathode swung outwardly;

FIG. 2 is a partial section through the apparatus of FIG. 1, though with the charging cover and sputtering cathode swung into position during the coating procedure, in which the substrate holder is situated beneath the sputtering cathode;

FIG. 3 is a perspective view of another embodiment of the invention, in which the two stations can be mutually sealed off by a partition with a valve; and

FIGS. 4 and 5 are plan views, partly in section and partly diagrammatic, of the FIG. 3 embodiment showing two possible views of substrate holder and valve closure.

FIG. 1 represents a cathode sputtering unit 1 with two adjacent stations 2 and 3, of which the station 2 preferably is simultaneously a charging station and etching station, while station 3 is a coating station. These stations preferably constitute part of a parallelepiped vacuum station 4 whose upper chamber wall 5 preferably has two circular recesses 6 and 7. One of them can be closed by a charging cover 8, which preferably can be swung sideways by means of a lifting drive 9 and a rotary drive 10 via a lever arm 11.

The other circular recess 7 can be closed by a sputtering cathode 12 preferably arranged together with its impedance matching supply 13 on a sealing flange 14 that can pivot about an eccentric shaft 15.

With regard to the recesses 6 and 7 one can imagine a vertical plane of symmetry between these recesses that preferably runs roughly through the cross arm 16 serving to reinforce the upper chamber wall 5. The vertical shaft of a pivot bearing 17 passing in an insulated manner through the lower chamber wall 18 of the vacuum chamber 4 preferably is arranged in this plane of symmetry. The lower end of the pivot bearing is not visible here, but is situated in a housing 19 accommodating a further impedance matching supply.

A radial extension arm 20 connected to a substrate holder 21 preferably is secured to the pivot bearing 17. The substrate holder 21 is located in the illustrated case coaxially underneath the recess 6, the individually applied substrates 22 being visible. If the charging cover 8 is now swung in a counter-clockwise direction over the recess 6 and then lowered to produce a vacuum-tight connection, an etching process can be performed in the station 2, for which the high frequency generator connected to the pivot bearing 17 provides the necessary energy.

After this etching process the substrate holder 21 can be swung so far in a clockwise direction by means of the pivot bearing 17 that it comes to rest coaxially underneath the recess 7. With the sputtering cathode 12 swung inwardly it is possible to perform a coating operation on the substrate 22 in this position.

In the present case a circular disc 23 can also be seen in the recess 7, which serves as a pre-sputtering plate. Impurities from the surface of the sputtering cathode 12 can be deposited on this circular disc at the beginning of the coating procedure. In order to free the path for the substrate holder 21, the circular disc 23 preferably is secured to a lifting drive 24 with which the circular disc can be lowered so that the substrate holder 21 can be moved into position exactly above the circular disc.

In FIG. 2 the same parts as in FIG. 1 are provided with the same reference numerals. It should be remembered in connection with FIG. 1 that the substrate holder 21 is formed as an essentially cylindrical hollow body in which a supporting plate 26 provided with cooling channels 25 is mounted on its upper side. This supporting plate has a number of circular disc-shaped recesses which are provided for positioning the substrates 22 in a position according to FIG. 1. A coolant circulation means 27, which is here symbolized only by a double branched line but which of course preferably comprises two lines for inflow and recycle, leads from the cooling channels 25 either to a heat exchanger or to an outflow. The term "coolant circulation" is understood to mean any passage of a liquid coolant through the substrate carrier 21.

It can be seen that the coolant circulation means 27 is passed through the pivot bearing 17. It can also be seen

that the circular disc 23 is illustrated in a lowered position relative to FIG. 1 so that there is sufficient space between it and the recess 7 to swing the substrate holder 21 in. The underneath of the sputtering cathode 12 comprises a target plate of the coating material to be sputtered, and in addition the surface of this target plate preferably is aligned parallel to the supporting plate 26. The sputtering cathode 12 preferably is also connected to a coolant circulation means 28, of which only one branch is shown.

A suction pipe 29 for evacuating the system as well as a supporting frame 30 are also represented in FIGS. 1 and 2.

FIG. 3 shows a cathode sputtering unit 31 modified with respect to FIGS. 1 and 2, and also with two stations 2 and 3 performing the same function as in FIG. 1. The charging cover 8 and the sputtering cathode 12 are represented only diagrammatically. In the present case a differently shaped extension arm 32 bent into an angle and situated in a horizontal plane (FIGS. 4 and 5) preferably is provided for connecting the substrate holder 21 to the pivot bearing 17 and for passage of the coolant circulation. A partition 33 with a first valve closure 34 preferably formed by a rectangular plate is situated between the two stations 2 and 3. This valve closure cooperates with a valve seat 35 whose contour roughly corresponds to the contour of the valve closure 34. A second valve closure 36 congruent to the first valve closure 34 preferably is secured in such a spatial position on the bent extension arm 32 that it comes to rest in a vacuum-tight manner on the valve seat 35 when the substrate holder 21 is swung from the station 2 (FIG. 4) into the station 3 (FIG. 5). Any cross-contamination between the stations 2 and 3 is thereby excluded.

It can be seen that the bent extension arm 32 passes through the second valve closure 36. Consequently the coolant circulation is also passed through the second valve closure so that the coolant circulation can be maintained in both station 2 and station 3 as well as during transportation between the two stations. The transportation movement is symbolized by the two circular arcs in FIGS. 4 and 5.

Heat-conducting substances include, for example, low melting point metals (gallium, m.p.=28.6° C.) or alloys (indium/gallium, m.p.=15.9° C.), as well as organic pastes to which good heat-conducting metal powders (silver or aluminum) have been added.

While there have been described what are at present considered to be the preferred embodiments of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is, therefore, aimed to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. Cathode sputtering apparatus comprising:
- a vacuum chamber;
- at least two adjacently arranged stations including a charging station and a coating station;
- at least one sputtering cathode means;
- a substrate holder able to execute reciprocal movement between said stations;
- a pivot bearing passing through said vacuum chamber;
- an extension arm on said pivot bearing;
- said substrate holder being secured by means of said extension arm eccentrically on said pivot bearing; and
- coolant circulation means led through said pivot bearing to said substrate holder.

2. Cathode sputtering apparatus according to claim 1, which includes a supporting plate provided with cooling channels and in which said substrate holder is formed as an essentially cylindrical hollow body having an upper side in which said supporting plate provided with cooling channels is mounted.

3. Cathode sputtering apparatus according to claim 1, which includes a high frequency generator and in which said substrate holder is mounted insulated with respect to said vacuum chamber and is coupled to said high frequency generator.

4. Cathode sputtering apparatus according to claim 1, which includes a charging cover and in which said vacuum chamber is parallelepiped-shaped and has an upper chamber wall having therein two circular recesses, one of which can be closed by said sputtering cathode means and the other of which can be closed by said charging cover, and in which said recesses have a vertical plane of symmetry therebetween, the axis of said pivot bearing lying in said vertical plane of symmetry running between said recesses.

5. Cathode sputtering apparatus according to claim 4, which includes a circular disc which can be raised and lowered as a pre-sputtering plate underneath said one of said recesses which can be closed by said sputtering cathode means.

6. Cathode sputtering apparatus according to claim 1, which includes a partition with a valve seat and a first valve closure arranged between said two stations and in which said extension arm has a second valve closure that can be brought to rest on said valve seat by swinging said substrate holder into said coating station.

7. Cathode sputtering apparatus according to claim 6, in which said extension arm is formed with an angle in a horizontal plane.

* * * * *

US006325857B1

(12) **United States Patent**
Miyoshi

(10) **Patent No.: US 6,325,857 B1**
(45) **Date of Patent: Dec. 4, 2001**

(54) **CVD APPARATUS**

(75) Inventor: **Yosuke Miyoshi**, Tokyo (JP)

(73) Assignee: **NEC Corporation**, Tokyo (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/434,189**

(22) Filed: **Nov. 4, 1999**

(30) **Foreign Application Priority Data**

Nov. 5, 1998 (JP) 10-315213

(51) **Int. Cl.**^{7} **C23C 16/00**
(52) **U.S. Cl.** .... **118/724**; 118/50.1; 118/723 HC; 118/723 DC
(58) **Field of Search** .... 118/724, 50.1, 118/723 HC, 723 DC

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Primary Examiner—Gregory Mills
Assistant Examiner—Luz L. Alejandro

(57) **ABSTRACT**

A CVD apparatus is provided, which is capable of cleaning the inside of a reaction chamber without affecting a catalyzer member after a CVD process is completed. This apparatus is comprised of a reaction chamber; a substrate stage located in the chamber, a substrate being placed on the stage; a catalyzer holder located in the chamber for holding a catalyzer member; the holder having an inner space in which the catalyzer member is fixed; the holder having an opening that communicates with the inner space and that faces toward the substrate placed on the stage; a shutter located in the chamber for closing the opening of the holder; a cleaning device for cleaning an inside of the chamber after a CVD process is completed; and a gas supply line for supplying a source gas into the inner space of the holder. When a film is formed on the substrate, the source gas is supplied into the inner space of the holder to generate an active species due to a catalysis of the catalyzer member, and the active species is supplied to the substrate placed on the stage through the opening of the holder. When the inside of the chamber is cleaned by the cleaning device, the substrate is taken out of the chamber and the opening of the holder is closed by the shutter, separating the catalyzer member located in the holder from an outside atmosphere of the holder.

8 Claims, 8 Drawing Sheets

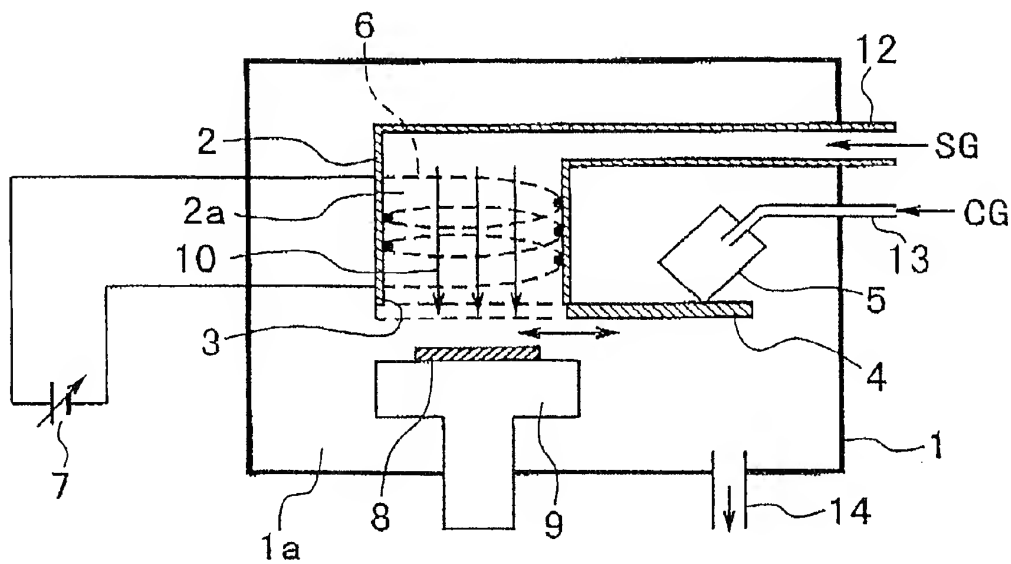


Exhibit F

FIG. 1
PRIOR ART

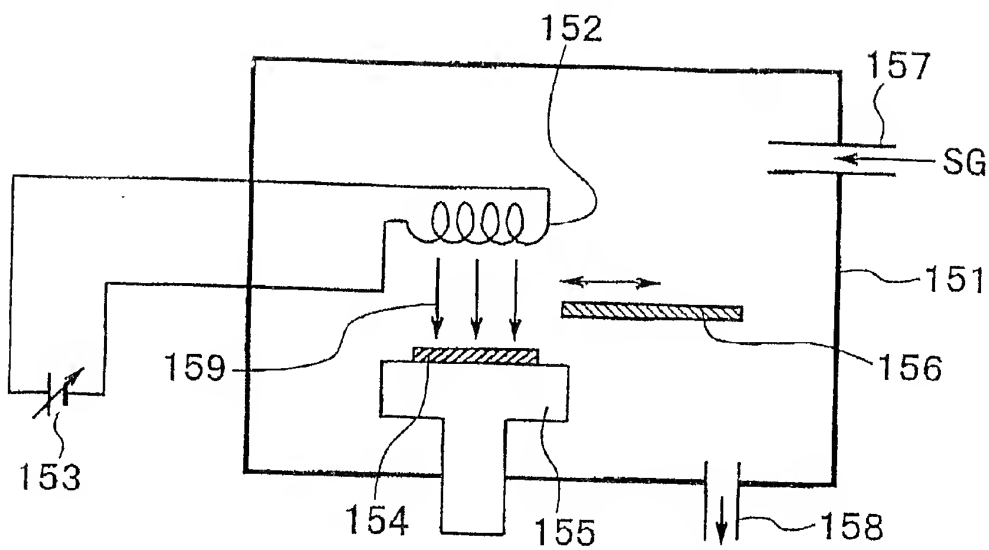


FIG. 2
PRIOR ART

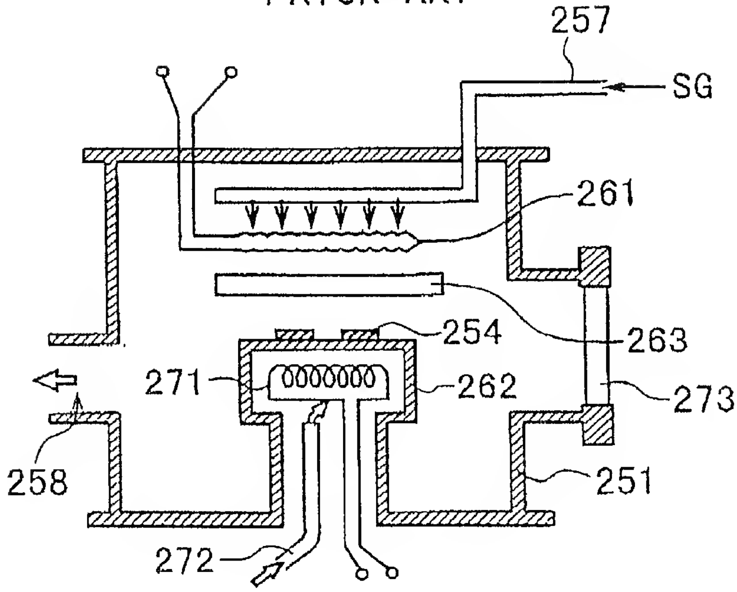


FIG. 3
PRIOR ART

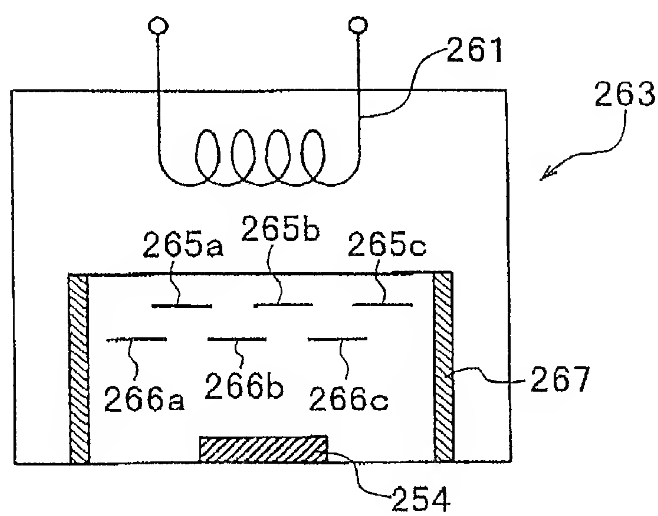


FIG. 4

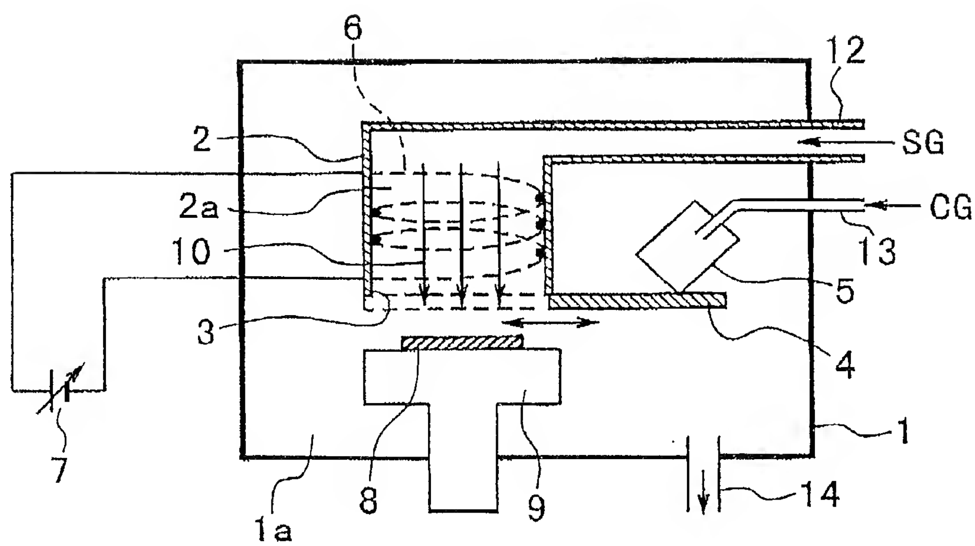


FIG. 5A

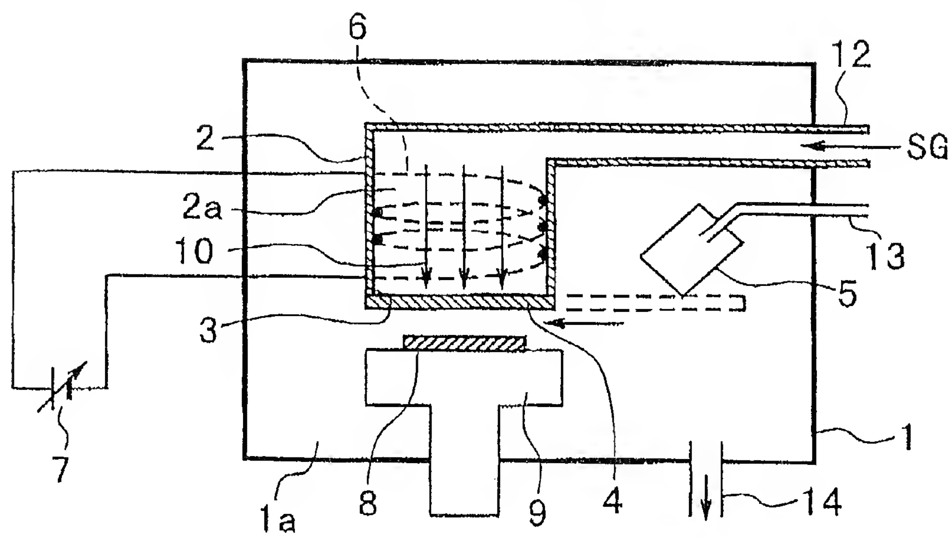


FIG. 5B

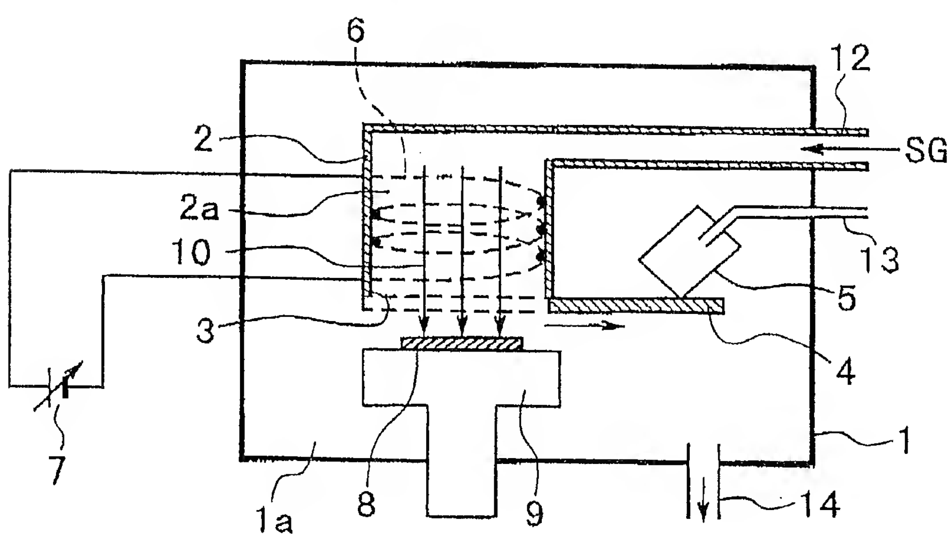


FIG. 5C

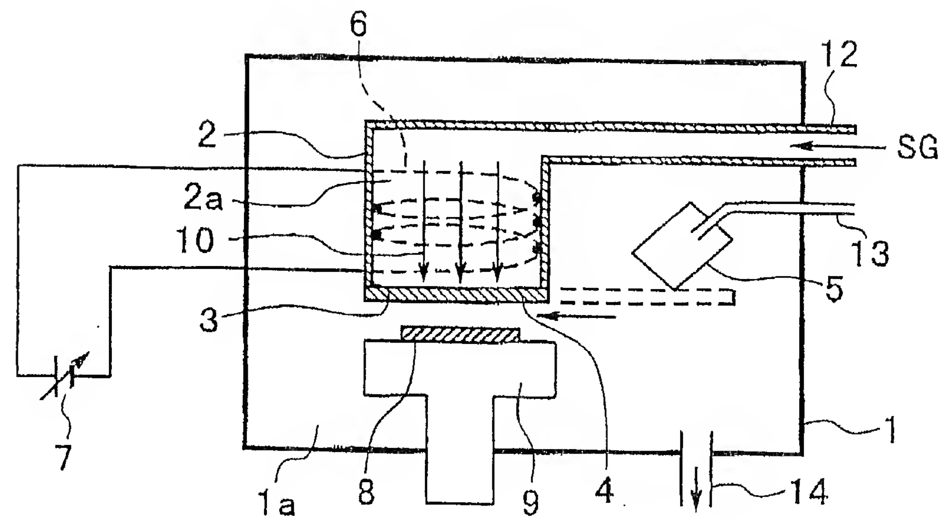


FIG. 5D

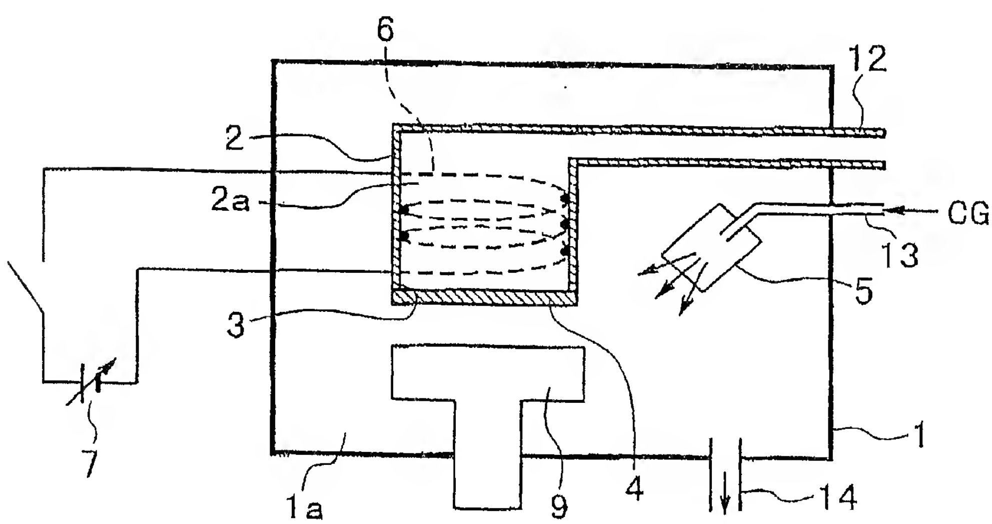
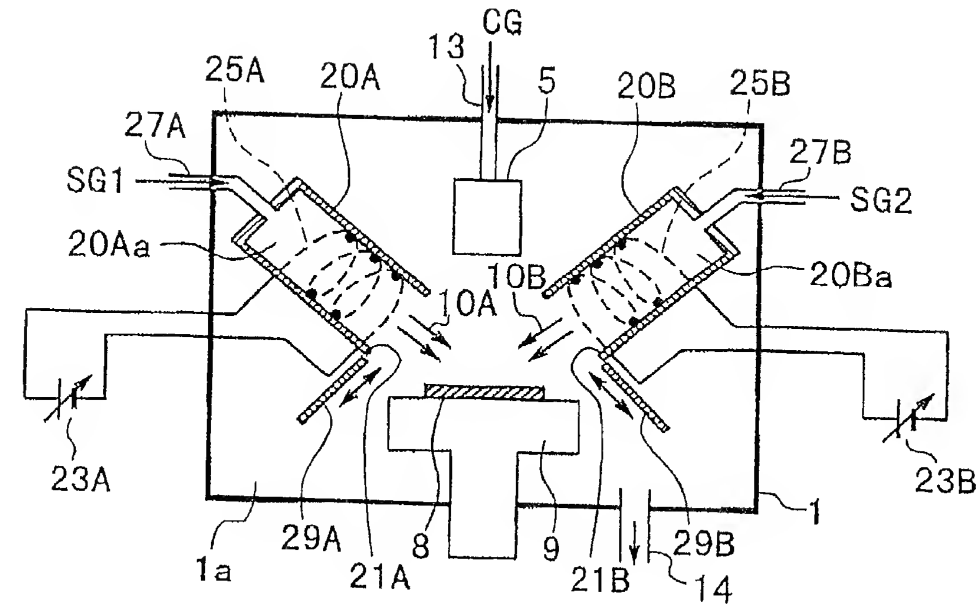


FIG. 6


CG
13
5
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SG2
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8
9
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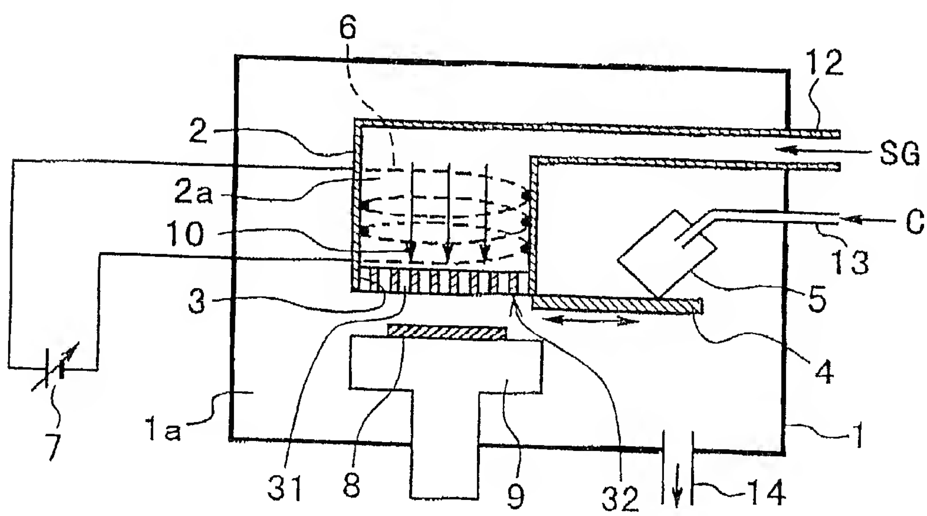
21A
21B
14

FIG. 7


6
12
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13
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3
4
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1
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32
14

FIG. 8

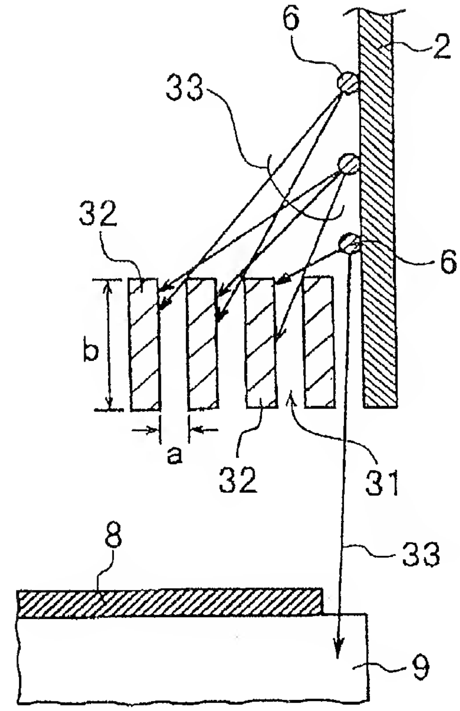


FIG. 9

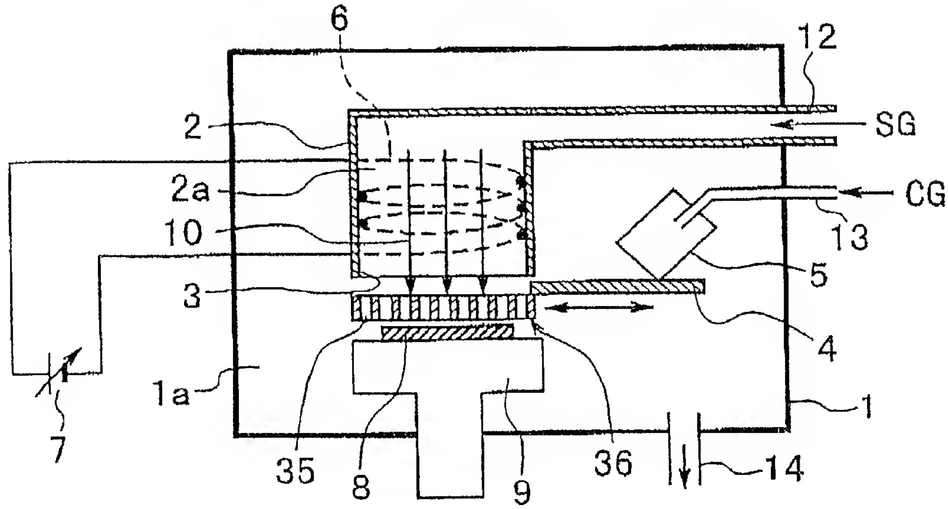


FIG. 10

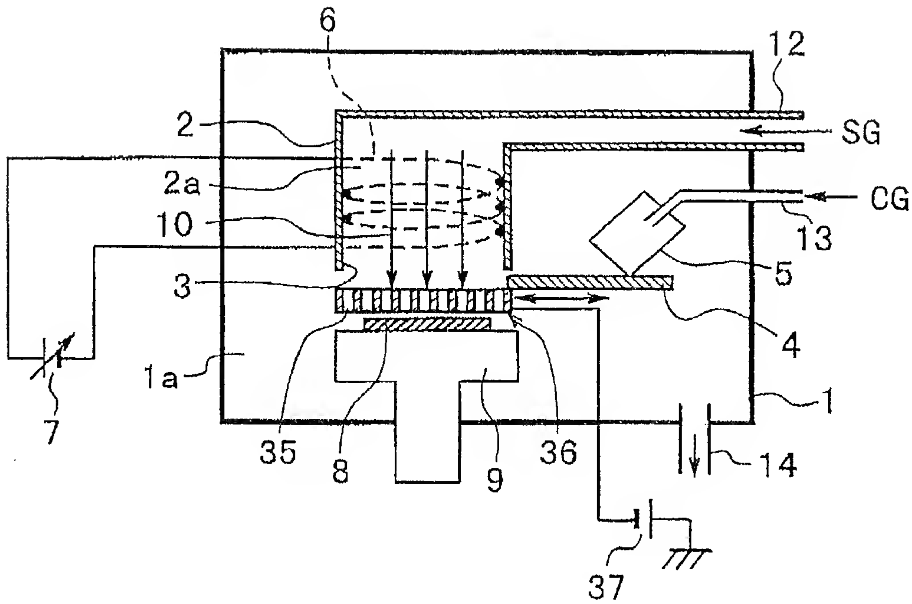
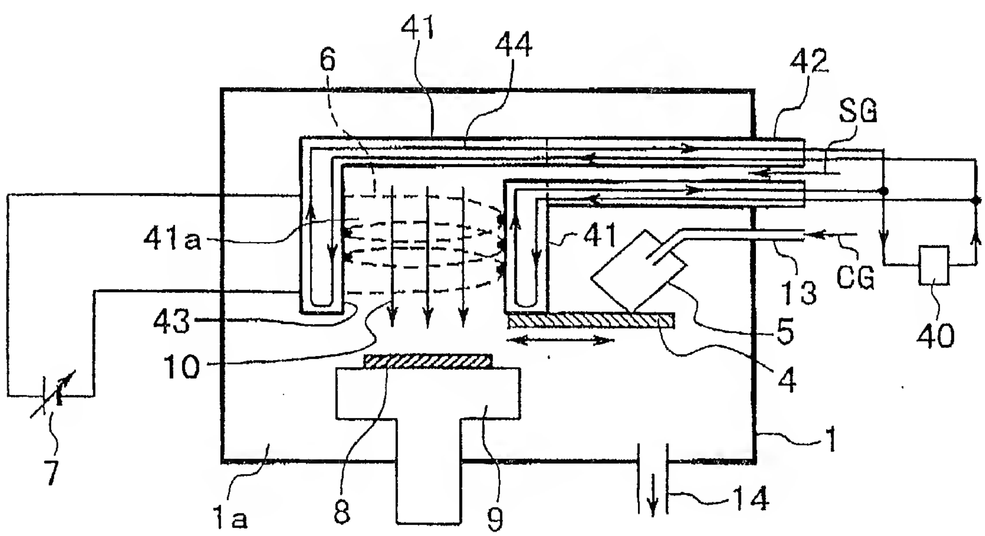

6
12
2
SG
2a
CG
10
13
5
3
4
1a
1
7
35
8
9
36
14
37

FIG. 11


41
44
6
42
SG
41a
41
13
CG
43
5
40
10
4
7
1
1a
8
9
14

CVD APPARATUS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to Chemical Vapor Deposition (CVD) for forming a desired film on a substrate using a catalyzer More particularly, the invention relates to a CVD apparatus that uses a catalyzer member for applying a catalysis to a CVD reaction or reactions and that is equipped with a cleaning device for cleaning the inside of the reaction chamber after a CVD process or processes is/are completed, and a film formation method using the CVD apparatus.

2. Description of the Prior Art

In the fabrication process sequence of semiconductor devices, for example, Large-Scale Integrated circuits (LSIs) designed for memories, microprocessors, and so on, various thin films need to be formed on a substrate These thin films include dielectric films, such as a silicon nitride (SiN_x) film which is used for an oxidation-resistant masking film in the isolation-dielectric formation proeess of Metal-Oxide-Semiconductor (MOS) LSIs, and a silicon dioxide (SiO_2) film which is used for a passivation film. Furthermore, they include conductive films, such as a polysilicon film which is used for forming gate electrodes and gate wiring lines in MOS LSIs, and a tungsten (W) film which is used for forming contact plugs of multilevel wiring structures

To form the above-described thin films, various CVD processes have been developed and extensively used in the semiconductor device fabrication field In these CVD processes, suitable catalyzers may be used to lower the necessary temperature of the substrate and to improve the quality of the films formed on the substrate. Here, these processes are termed "catalytic CVD processes".

In a typical catalytic CVD process, a suitable catalyzer member (which is made of, for example, a refractory metal) is placed in a reaction chamber along with a substrate. The substrate and the catalyzer member are heated to specific temperatures, respectively. Then, suitable gaseous source materials are then supplied to the chamber, thereby forming a desired film on the surface of the substrate through a specific CVD reaction or reactions under the catalysis of the catalyzer member. There is a benefit that the thin film thus formed has a satisfactorily good quality even when the temperature of the substrate is comparatively low.

FIG. 1 schematically shows the configuration of a prior-art catalytic CVD apparatus used for performing a catalytic CVD process.

In FIG. 1, the CVD apparatus is comprised of a reaction chamber **151** made of quartz and a coil-shaped catalyzer member **152** placed in the chamber **151**. The catalyzer member **152** is formed by a piece of wire made of a refractory metal such as tungsten (W). The catalyzer member **152** is electrically connected to a power supply **153** placed outside the chamber **151** for heating the member **152** to a specific temperature on operation. A substrate stage **155** on which a single-crystal silicon (Si) substrate **154** is placed is fixed in the chamber **151**. The stage **155** is positioned right below the catalyzer member **152**.

A shutter **156**, which is horizontally movable along the horizontal arrow in FIG. 1, is provided in the chamber **151** between the catalyzer member **152** and the substrate stage **155**. The shutter **156** can be positioned at a closing position and an opening position. At the closing position, the shutter **156** is located just over the substrate **154** placed on the stage **155** and entirely covers the surface of the substrate **154**. At the opening position, the shutter **156** is located apart from the substrate **154** and entirely exposes the surface of the substrate **154**, allowing active species **159** generated in the vicinity of the catalyzer member **152** to reach the substrate **154**.

A gas inlet **157** is provided at an upper position of the side wall of the reaction chamber **151**. Source or reactant gas or gases SG is/are supplied into the reaction chamber **151** through the gas inlet **157**. A gas outlet **158** is provided at the bottom wall of the chamber **151**. Gaseous substances existing in the chamber **151** are exhausted to the outside of the chamber **151** through the gas outlet **158**.

The above-described prior-art CVD apparatus is used in the following way, in which a thin SiN_x film used as a dielectric in the semiconductor device is formed on the substrate **154**.

First, the Si substrate or wafer **154** is sent to the inside of the reaction chamber **151** and is placed on the substrate stage **155**. The substrate **154** is then heated up to a specific temperature ranging from 300 to 400° C. and kept at the same temperature by using a heater (not shown) incorporated into the stage **155**.

Next, while the shutter **156** is located at the closing position just over the substrate **154**, the catalyzer member **152** is heated up to a specific high temperature ranging from 1700 to 1800° C. and kept at the same temperature by using the power supply **153**. Thereafter, as the source or reactant gases SG, gaseous monosilane (SiH_4) and ammonia (NH_3) are introduced into the chamber **151** through the gas inlet **157** at their specific flow rates. The introduced SiH_4 and NH_3 are decomposed due to the catalysis of the heated catalyzer member **152**, generating the active species **159** in the vicinity of the member **152**. Because of the shutter **156** at the closing position, the active species **159** thus generated do not reach the substrate **154** at this stage.

After the flow rates of the gaseous SiH_4 and NH_3 and the temperature of the catalyzer member **152** become steady, the shutter **156** is horizontally moved to the opening position to thereby expose entirely the surface of the substrate **154** to the active species **159**, as shown in FIG. 1. Thus, the active species **159** generated from the SiH_4 and NH_3 gases SG begin to be supplied to the surface of the substrate **154**, as shown by the vertical arrows in FIG. 1. The active species **159** react with the Si atoms of the substrate **154** and deposit SiN_x on the surface of the substrate **154**. After a specific deposition period passes, the shutter **156** is moved to the closing position again, completing the deposition process. Thus, a desired SiN_x film (not shown) with a desired thickness is formed on the surface of the Si substrate **154**.

In the prior-art catalytic CVD apparatus shown in FIG. 1, thereafter, the substrate **154** with the deposited SiN_x film is taken out of the reaction chamber **151** and then, a cleaning process is conducted to clean the inside of the chamber **151**, i.e., to removed the unwanted SiN_x films deposited on the inner walls of the chamber **151** or the like. This cleaning proeess is carried out by an unillustrated cleaning deviee or subsystem. A next CVD process is then conducted in the same reaction chamber **151** in the same way as above.

In popular CVD apparatuses, a cleaning subsystem is equipped for the purpose of cleaning the inside of a reaction chamber. Typically, gaseous carbon tetrafluoride (CF_4) is used as a cleaning gas. After a CVD process is completed, the cleaning gas is introduced into the reaction chamber and then, CF_4 plasma is generated from the gaseous CF_4 using a popular plasma generator. The CF_4 plasma thus generated removes the unwanted SiN_x films existing in the inside of the reaction chamber by etching.

As seen from the above explanation, the prior-art catalytic CVD apparatus shown in FIG. 1 has a problem that the catalyzer member 152 itself is etched by the CF_4 plasma during the cleaning process, resulting in breaking or degradation of the coil-shaped catalyzer member 152. In other words, in the prior-art catalytic CVD apparatus of in FIG. 1, there is a problem that the inside of the reaction chamber 151 is difficult to be cleaned.

Moreover, the prior-art catalytic CVD apparatus of FIG. 1 has another problem that the temperature of the substrate 154 tends to be raised due to the heat radiated from the heated catalyzer member 152 during the deposition process. This is because the catalyzer member 152 is typically placed at a short distance (e.g., 4 cm to 5 cm) from the substrate 154. As known well, the thickness of the deposited SiN_x film is determined mainly by the temperature of the substrate 154 and therefore, the temperature rising of the substrate 154 during the CVD process will cause unwanted thickness fluctuation of the SiN_x film on the same substrate 154.

FIGS. 2 and 3 show another prior-art catalytic CVD apparatus disclosed in the Japanese Patent No. 2,692,326 published in December 1997 (which corresponds to the Japanese Non-Examined Patent Publication No. 3-239320 published in October 1990). This prior-art apparatus is capable of suppressing the effect of radiated heat from a catalyzer member during a deposition or CVD process, solving the latter problem relating the temperature rise of a substrate.

As shown in FIG. 2, a coil-shaped catalyzer member 261 is placed in a reaction chamber 251. The catalyzer member 261 is electrically connected to a power supply (not shown) provided outside the chamber 251 for heating the catalyzer member 261 to a specific temperature on operation. A substrate stage 262 on which substrates 254 are placed is fixed in the chamber 251 The stage 262 is positioned right below the catalyzer member 261. A radiation-shielding member 263 is provided in the chamber 251 between the catalyzer member 261 and the stage 262.

A gas-supplying tube 257 is provided to penetrate the top wall of the reaction chamber 251. A source gas or gases SG is/are supplied through the tube 257 to the inside of the chamber 251. The end part of the tube 257, which is placed in the chamber 251, has small nozzle-shaped holes. The source gas or gases SG is/are vertically emitted through the nozzle-shaped holes into the chamber 151, as shown by the vertical allows in FIG. 2. The catalyzer member 261 is located near and below the holes of the tube 257.

A gas outlet 258 is provided at the side wall of the reaction chamber 251. Gaseous substances existing in the chamber 251 are exhausted to the outside of the chamber 251 through the gas outlet 258.

A heater 271 and a cooling tube 272 are provided in the substrate stage 262. The heater 271 is used to heat the substrates 254 placed on the stage 262 by supplying electric power. The cooling tube 272 is used to cool the substrates 254 placed on the stage 262 by flowing a cooling water through the tube 272. A window 273, through which the inside of the chamber 251 can be seen, is provided at the side wall of the chamber 251.

As shown in FIG. 3, the radiation-shielding member 263 is comprised of a cylindrical member 267, three upper plate members 265*a*, 265*b*, and 265*c* arranged at specific intervals to form slits in a horizontal plane, and lower plate members 266*a*, 266*b*, and 266*c* arranged at specific intervals to form slits in another horizontal plane. These members 265*a*, 265*b*, 265*c*, 266*a*, 266*b*, and 266*c* are formed by elongated stainless-steel plates. The upper plate members 265*a*, 265*b*, and 265*c* are located over the lower plate members 266*a*, 266*b*, and 266*c* at a specific gap. The upper plate members 265*a*, 265*b*, and 265*c* are shifted in a horizontal direction so as to partially overlapped with the lower plate members 266*a*, 266*b*, and 266*c*.

Due to existence of the radiation-shielding member 263, the heat radiated from the catalyzer member 261 is prevented from reaching directly the substrates 254 while allowing the source gas or gases SG or active species to reach the substrates 254 through the slits of the member 263.

With the above-described prior-art CVD apparatus shown in FIGS. 2 and 3, the above-described latter problem about the temperature rise of the substrates 254 can be solved by the radiation-shielding member 263. However, the above-described former problem about the cleaning process is left unsolved.

SUMMARY OF THE INVENTION

Accordingly, an object of the present invention to provide a catalytic CVD apparatus capable of cleaning the inside of a reaction chamber without affecting a catalyzer member after a CVD process is completed.

Another object of the present invention to provide a catalytic CVD apparatus that suppresses the effect of radiated heat from a heated catalyzer member to a substrate.

Still another object of the present invention to provide a film formation method capable of cleaning the inside of a reaction chamber of a catalytic CVD apparatus without affecting a catalyzer member provided in the reaction chamber after a CVD process is completed.

A further object of the present invention to provide a film formation method that suppresses the effect of radiated heat from a heated catalyzer member to a substrate.

The above objects together with others not specifically mentioned will become clear to those skilled in the art from the following description.

According to a first aspect of the present invention, a catalytic CVD apparatus is provided, which is comprised of

a reaction chamber;

a substrate stage located in the chamber, a substrate being placed on the stage;

a catalyzer holder located in the chamber for holding a catalyzer member;

the holder having an inner space in which the catalyzer member is fixed;

the holder having an opening that communicates with the inner space and that faces toward the substrate placed on the stage;

a shutter located in the chamber for closing the opening of the holder;

a cleaning device for cleaning an inside of the chamber after a CVD process is completed; and

a gas supply line for supplying a source gas into the inner space of the holder.

When a film is formed on the substrate, the source gas is supplied into the inner space of the catalyzer holder to generate an active species due to a catalysis of the catalyzer member, and the active species is supplied to the substrate placed on the stage through the opening of the catalyzer holder.

When the inside of the chamber is cleaned by the cleaning device, the substrate is taken out of the chamber and the opening of the holder is closed by the shutter, separating the

catalyzer member located in the holder from an outside atmosphere of the holder.

With the catalytic CVD apparatus according to the first aspect of the present invention, the catalyzer holder is located in the reaction chamber to hold the catalyzer member, and the catalyzer member is fixed in the inner space of the holder. A source gas is supplied into the inner space of the holder through the gas supply line to be contacted with the catalyzer member, generating an active species The active species thus generated is supplied to the surface of the substrate placed on the stage through the opening of the holder, thereby forming a desired film on the substrate. Accordingly, the CVD process can be performed in a similar way to that of a CVD apparatuses without the catalyzer holder.

On the other hand, when the inside of the reaction chamber is cleaned by the cleaning device, the substrate is taken out of the chamber and the opening of the catalyzer holder is closed by the shutter, separating the catalyzer member located in the holder from the outside atmosphere of the holder. As a result, the inside of the reaction chamber can be cleaned without affecting the catalyzer member after a CVD process is completed.

In a preferred embodiment of the CVD apparatus according to the first aspect of the present invention, an additional catalyzer holder is located in the chamber for holding an additional catalyzer member. The additional holder has an inner space in which the additional catalyzer member is fixed. The additional holder has an opening that communicates with the inner space and that faces toward the substrate placed on the stage. An additional shutter is located in the chamber for closing the opening of the additional holder.

In this embodiment, there is an additional advantage as follows: When the source gas is made of the mixture of different gases, the ratio of the different gases can be accurately controlled so that the film deposited on the substrate is stoichiometric. Moreover, the different gases can be used effectively, in other words, the utilization rate of the gases is improved.

In another preferred embodiment of the apparatus according to the first aspect of the present invention, a grid member having penetrating holes for allowing the active species to reach the substrate placed on the stage is further provided. In this embodiment, there is an additional advantage that the effect of radiated heat from the heated catalyzer member to the substrate is suppressed by the grid member.

The grid member may be located inside or outside the holder as necessary.

If the grid member is located inside the holder, the grid member is separated from the outside atmosphere of the holder when the shutter closes the opening of the holder. In this case, there is an additional advantage that the grid member is not affected by a cleaning agent produced from the cleaning gas during the cleaning process.

If the grid member is located outside the holder, the grid member is not separated from the outside atmosphere of the holder even when the shutter closes the opening of the holder. In other words, the grid member is affected by a cleaning agent during the cleaning process. Therefore, there is an additional advantage that the deposition rate of the film on the substrate can be prevented from lowering, because the grid member is cleaned by the cleaning agent during the cleaning process.

It is preferred that the grid member is designed for being applied with a negative bias voltage. In this embodiment, there is an additional advantage that the amount or thickness of the deposited film on the grid member is decreased.

In still another preferred embodiment of the apparatus according to the first aspect of the present invention, the holder includes a path for allowing a cooling medium to flow through the wall of the holder. In this embodiment, there is an additional advantage that the quality of the deposited film on the substrate is more controllable, because the temperature of the catalyzer member can be controlled, making the effect of the radiated heat from the heated catalyzer member more controllable.

In a further preferred embodiment of the apparatus according to the first aspect of the present invention, the gas supply line is communicated with an upper part of the catalyzer holder, and the source gas supplied into the inner space of the holder flows downward to be contacted with the catalyzer member. In this embodiment, there is an additional advantage that the supplied source gas is surely contacted with the catalyzer member in the catalyzer holder.

According to a second aspect of the present invention, a film formation method is provided, which is comprised of the following steps (a) to (e):

(a) A substrate is placed on a substrate stage located in a reaction chamber of a catalytic CVD apparatus. The chamber includes a catalyzer holder for holding a catalyzer member. The holder has an inner space in which the catalyzer member is fixed. The holder has an opening that communicates with the inner space and that faces toward the substrate placed on the stage. The opening of the holder is closed or opened by a shutter located in the chamber.

(b) A source gas is supplied to the inner space of the catalyzer holder through a gas supply line to be contacted with the heated catalyzer member, generating an active species in the holder.

(c) A desired film is formed on the substrate due to a reaction between the active species and a substance of the substrate.

(d) The opening of the holder is closed by the shutter after the desired film is completely formed on the substrate.

(e) A cleaning device is activated to clean an inside of the chamber while the catalyzer member is separated from an outside atmosphere of the holder by closing the opening of the holder by the shutter.

With the film formation method according to the second aspect of the present invention, after a desired film is formed on the substrate in the step (c), the opening of the holder is closed by the shutter in the step (d). Then, the cleaning device is activated to clean the inside of the reaction chamber while the catalyzer member is separated from the outside atmosphere of the catalyzer holder by closing the opening of the holder by the shutter in the step (e).

As a result, the inside of the reaction chamber of the catalytic CVD apparatus can be cleaned without affecting the catalyzer member provided in the reaction chamber after a CVD process is completed.

In a preferred embodiment of the method according to the second aspect of the present invention, the reaction chamber further includes a grid member having penetrating holes for allowing the active species to reach the substrate placed on the stage. In this embodiment, there is an additional advantage that the effect of radiated heat from the heated catalyzer member to the substrate is suppressed by the grid member.

The grid member may be located inside or outside the catalyzer holder as necessary.

In another preferred embodiment of the method according to the second aspect of the present invention, the gas supply line is communicated with an upper part of the catalyzer holder, and the source gas supplied into the inner space of the holder flows downward to be contacted with the cata-

lyzer member. In this embodiment, there is an additional advantage that the supplied source gas is surely contacted with the catalyzer member in the catalyzer holder.

In still another preferred embodiment of the method according to the second aspect of the present invention, the opening of the holder is closed by the shutter until a flow of the supplied source gas and a temperature of the heated catalyzer member become approximately steady in the step (b). In this embodiment, there is an additional advantage that the quality and the thickness of the deposited film on the substrate are controlled more accurately.

BRIEF DESCRIPTION OF THE DRAWINGS

In order that the present invention may be readily carried into effect, it will now be described with reference to the accompanying drawings.

FIG. 1 is a schematic cross-sectional view of a main part of a prior-art CVD apparatus.

FIG. 2 is a schematic cross-sectional view of a main part of another prior-art CVD apparatus.

FIG. 3 is a schematic, enlarged cross-sectional view of the radiation-screening device or member of the prior-art CVD apparatus shown in FIG. 2.

FIG. 4 is a schematic cross-sectional view of a main part of a CVD apparatus according to a first embodiment of the present invention.

FIGS. 5A and 5D are schematic cross-sectional views of the main part of the CVD apparatus according to the first embodiment of FIG. 4, respectively, in which a film is formed on a substrate in the reaction chamber and then, the inside of the chamber is cleaned.

FIG. 6 is a schematic cross-sectional view of a main part of a CVD apparatus according to a second embodiment of the present invention.

FIG. 7 is a schematic cross-sectional view of a main part of a CVD apparatus according to a third embodiment of the present invention.

FIG. 8 is a schematic, enlarged cross-sectional view of the grid member of the CVD apparatus according to the third. embodiment of FIG. 7.

FIG. 9 is a schematic cross-sectional view of a main part of a CVD apparatus according to a fourth embodiment of the present invention.

FIG. 10 is a schematic cross-sectional view of a main part of a CVD apparatus according to a fifth embodiment of the present invention.

FIG. 11 is a schematic cross-sectional view of a main part of a CVD apparatus according to a sixth embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Preferred embodiments of the present invention will be described in detail below while referring to the drawings attached.

FIRST EMBODIMENT

As shown in FIG. 4, a catalytic CVD apparatus according to a first embodiment of the present invention is comprised of a reaction chamber **1**, a cylindrical catalyzer holder **2** for holding a coil-shaped catalyzer member **6** in its inner space **2***a*, a plate-shaped shutter **4** for closing or opening a bottom opening **3** of the holder **2**, and a cleaning device **5** for cleaning the inside of the chamber **1**. The catalyzer holder **2**, the shutter **4**, the cleaning device **5**, and the catalyzer member **6** are located in the chamber **1**. The cleaning device **5** is located outside the holder **2**.

The reaction chamber **1** is made of a heat-resistant material such as quartz and has a popular configuration. The catalyzer holder **2** is made of a heat-resistant, electrical insulating material such as ceramic. The inner space **2***a* of the holder **2** has a cylindrical shape whose longitudinal axis is vertically arranged. The opening **3** of the holder **2** is formed at the bottom of the space **2***a*. The shutter **4** is made of a heat-resistant material.

The coil-shaped catalyzer member **6** is formed by a piece of wire made of a refractory metal such as W. The member **6** is fixed onto the inner wall of the catalyzer holder **2**. The member **6** is electrically connected to a power supply **7** placed outside the chamber **1** for heating the member **6** to a specific temperature on use. To take the degradation or deterioration of the member **6** due to long-term use into consideration, the holder **2** is designed to be removable from the chamber **1** along with the catalyzer member **6**. A gas-supplying tube **12** is connected to another opening of the holder **2** and therefore, a desired source gas or gases SG is/are introduced into the inner space **2***a* of the holder **2**. The source gas(es) SG thus introduced is/are further supplied to the inside of the chamber **1** through the opening **3** of the holder **2**.

A substrate stage **9** on which a single-crystal Si substrate **8** is placed is fixed in the reaction chamber **1**. The stage **9** is positioned right below the opening **3** of the catalyzer member **6**. A heater (not shown) is incorporated into the stage **9** to heat the substrate **8** located thereon. The shutter **4**, which is horizontally movable along the horizontal arrow in FIG. **4**, is provided between the bottom end of the holder **2** and the stage **9**. The shutter **4** can be positioned at a specific closing position and a specific opening position. At the closing position, the shutter **4** closes the opening **3** of the holder **2** and entirely covers the underlying substrate **8**. At the opening position, the shutter **4** opens entirely the opening **3**, thereby exposing entirely the substrate **8**.

A gas tube **13** is provided to penetrate the side wall of the chamber **1**. The end of the tube **13** is connected to the cleaning device **5**. A cleaning gas CG is supplied to the cleaning device **5** through the tube **13**. The cleaning device **5** may be configured by, for example, a known Electron Cyclotron Resonance (ECR) plasma generator.

A gas outlet **14**, through which existing gaseous substances in the chamber **1** are exhausted, is provided at the bottom wall of the chamber **1**.

The above-described catalytic CVD apparatus according to the first embodiment is used in the following way, in which a thin SiN_x film to be used as a dielectric in the semiconductor device is formed on the Si substrate **8**.

First, as shown in FIG. 5A, the shutter **4** is moved to the closing position, closing the opening **3** of the catalyzer holder **2**. Thus, the catalyzer member **6** fixed in the inner space **2***a* of the holder **2** is separated from the inside atmosphere **1***a* of the reaction chamber **1**.

Next, the Si substrate or wafer **8**, to which suitable pretreatment has been applied, is sent to the inside of the chamber **1** and then, placed on the substrate stage **9**. The substrate **9** is then heated up to a specific temperature ranging from 300 to 400° C. and kept at the same temperature by using the heater (not shown) incorporated into the stage **9**.

Since the heat capacity of the stage **9** is greater than that of the substrate **8**, it is popular that the stage **9** is heated up

to a specific temperature in advance. Therefore, after the introduction of the substrate **8** into the chamber **1**, an intended CVD or film-formation process is preferably started at a time approximately one or two minutes have passed from the start of the heating step of the substrate **8**. Then, the atmospheric air existing in the chamber **1** is exhausted by a vacuum pump system (not shown), thereby setting the pressure of the chamber **1** at approximately 10 Pa. At this stage, the shutter **4** is placed at its opening position.

Subsequently, the catalyzer member **6** fixed in the holder **2** is supplied with electric power from the power supply **7**, thereby heating the member **6** up to a specific temperature ranging from 1700 to 1800° C. and keeping it at the same temperature due to the Joule heat. At this time, the temperature of the member **6** reaches the specific temperature in a comparatively short period of time. However, to shorten the processing time, the member **6** is preferably preheated prior to the introduction of the source gases SG into the chamber **1**.

After the opening **3** of the holder **2** is closed by the shutter **4**, gaseous SiH_4 is introduced into the inner space **2a** of the catalyzer holder **2** through the tube **12** at a flow rate of approximately 1 standard cubic centimeter per minute (sccm) and at the same time, gaseous NH_3 is introduced into the same space **2a** through the same tube **12** at a flow rate of approximately 100 sccm. The introduced source gases, i.e., SiH_4 and NH_3, are decomposed due to the catalysis of the heated catalyzer member **6**, generating active species **10** in the space **2a** of the holder **2**. Since the opening **3** of the holder **2** is closed by the shutter **4** at this time, the active species **10** thus generated do not reach the substrate **8**. As a result, no SiN_x film is deposited on the substrate **8**.

After the flow rates of the SiH_4 and NH_3 gases and the temperature of the catalyzer member **6** become steady, the shutter **4** is horizontally moved to the opening position, opening the opening **3** of the holder **2**. Thus, the upper region of the substrate **8** is exposed entirely, as shown in FIG. **5B**. Thus, the active species **10** generated from the SiH_4 and NH_3 gases in the holder **2** are supplied to the surface of the substrate **8**, as shown by the vertical arrows in FIG. **5B**. The active species **10** then react with the Si of the substrate **8** to deposit SiN_x on the surface of the substrate **8**. After a specific deposition period passes, the shutter **4** is moved to the closing position, closing the opening **3** of the holder **2**, as shown in FIG. **5C**. Thus, a desired SiN_x film (not shown) with a desired thickness is formed on the surface of the Si substrate **8**.

The thickness of the SiN_x film can be adjusted by the tire period from the opening to the closing of the shutter **4**. Therefore, there arises an advantage that not only the thickness fluctuation of the SiN_x films between the substrates **8** but also the thickness fluctuation of the same SiN_x film on each substrate **8** is decreased.

Then, the introduction or supply of the SiH_4 and NH_3 gases and the heating of the catalyzer member **6** are stopped. The unreacted SiH_4 and NH_3 gases existing in the chamber **1** and other gaseous substances produced by the CVD reaction or reactions are exhausted through the gas outlet tube **14**. Thereafter, the substrate **8** with the deposited SiN_x film is taken out of the reaction chamber **1**.

Subsequently, a cleaning process is conducted to clean the inside of the reaction chamber **1** by using the cleaning device **5** while the opening **3** of the catalyzer holder **2** is closed by the shutter **4**, as shown in FIG. **5D**. Thus, the unwanted SiN_x films deposited on the inner walls of the chamber **1**, the shutter **4**, and the substrate stage **9**, or the like are removed. The unwanted SiN_x films are etched away by CF_4 or CHF_3 plasma generated by the ECR plasma generator in the cleaning device **5**. The cleaning process is conducted in a specific time period.

Through the above-described CVD process of the SiN_x film and the cleaning process of the chamber **1**, one cycle of the SiN_x film formation is completed. A same CVD process and a same cleaning process are then repeated in the same chamber **1** in the same way as described above as necessary.

With the catalytic CVD apparatus according to the first embodiment of the present invention, the catalyzer holder **2** is provided in the reaction chamber **1** and the opening **3** of the holder **2** is closed or opened by the shutter **4**. Also, the inside of the chamber **1** is cleaned by the cleaning device **5** while closing the opening **3** of the holder **2**. Therefore, there is an advantage that the inside of the chamber **1** can be cleaned without affecting the catalyzer member **6**.

SECOND EMBODIMENT

FIG. **6** shows the configuration of a CVD apparatus according to a second embodiment of the present invention, which has the same configuration as that of the first embodiment of FIG. **4** except that first and second catalyzer holders **20A** and **20B** are provided instead of the catalyzer holder **2**. Therefore, the explanation about the same configuration is omitted here for the sake of simplification by attaching the same reference symbols as those used in FIG. **4** to the same or equivalent elements in FIG. **6**.

As shown in FIG. **6**, the first cylindrical catalyzer holder **20A** is located in the chamber **1** at its left-hand side so that a bottom opening **21A** of the first holder **20A** is directed toward the substrate stage **9**. The second cylindrical catalyzer holder **20B** is located in the chamber **1** at its right-hand side so that a bottom opening **21B** of the second holder **20B** is directed toward the substrate stage **9**. The opening **21A** of the first holder **20A** is closed or opened by a first shutter **29A**. The opening **21B** of the second holder **20B** is closed or opened by a second shutter **29B**.

A first coil-shaped catalyzer member **25A**, which is formed by a piece of wire made of a refractory metal such as W, is fixed in the inner space **20Aa** of the first holder **20A**. The member **25A** is fixed onto the inner wall of the holder **20A**. A second coil-shaped catalyzer member **25B**, which is formed by a piece of wire made of a refractory metal such as W, is fixed in the inner space **20Ba** of the second holder **20B**. The member **25B** is fixed onto the inner wall of the holder **20B**.

Each of the first and second catalyzer holders **20A** and **20B** is made of a heat-resistant material such as ceramic. Each of the first and second shutters **29A** and **29B** is made of a heat-resistant material.

The first catalyzer member **25A** is electrically connected to a first power supply **23A** placed outside the chamber **1** for heating the member **25A** to a specific temperature on use. The second catalyzer member **25B** is electrically connected to a second power supply **23B** placed outside the chamber **1** for heating the member **25B** to a specific temperature on use. To take the degradation or deterioration of the members **25A** and **25B** due to long-term use into consideration, the holders **20A** and **20B** with the members **25A** and **25B** are designed to be removable from the chamber **1** along with the members **25A** and **25B**, respectively.

A first gas-supplying tube **27A** is connected to another opening of the first holder **20A** and therefore, a first source gas SG1 is introduced into the inner space **20Aa** of the first holder **20A**. The source gas SG1 thus introduced is then

supplied to the vicinity of the substrate **8** through the opening **21**A. A second gas-supplying tube **27**B is connected to another opening of the second holder **20**B and therefore, a second source gas SG2 is introduced into the inner space **20**B*a* of the second holder **20**B. The source gas SG2 thus introduced is then supplied to the vicinity of the substrate **8** through the opening **21**B.

Unlike the first embodiment of FIG. **4**, the cleaning device **5** is located on the top wall of the chamber **1** between the first and second holders **20**A and **20**B.

The above-described catalytic CVD apparatus according to the second embodiment of FIG. **6** is used in the following way, in which a thin SiN_x film used as a dielectric in the semiconductor device is formed on the Si substrate **8**.

First, the first and second shutters **29**A and **29**B are moved to their closing positions, closing the openings **21**A and **21**B of the first and second catalyzer holders **20**A and **20**B, respectively. Thus, the first and second catalyzer members **25**A and **25**B are separated from the inside atmosphere **1***a* of the chamber **1**.

Next, the Si substrate **8** is sent to the inside of the chamber **1** and is placed on the substrate stage **9**. The substrate **9** is then heated up to a specific temperature and kept at the same temperature in the same way and condition as those of the first embodiment. The atmospheric air existing in the chamber **1** is then exhausted in the same way and condition as those of the first embodiment.

Subsequently, the first and second catalyzer members **25**A and **25**B fixed in the first and second holders **20**A and **20**B are respectively supplied with electric power from their power supplies **23**A and **23**B, thereby heating the members **25**A and **25**B up to a specific temperature and keeping it at the same temperature in the same way and condition as those of the first embodiment.

As the first source gas SG1, gaseous SiH_4 is introduced into the inner space **20**A*a* of the first holder **20**A through the tube **27**A at a flow rate of approximately 1 sccm. At the same time as this, as the second source gas SG2, gaseous NH_3 is introduced into the inner space **20**Ba of the second holder **20**B through the tube **27**B at a flow rate of approximately 100 sccm. The introduced first and second source gases SG1 and SG2 are respectively decomposed due to the catalysis of the heated catalyzer members **25**A and **25**B, generating active species **10**A in the inner space **20**A*a* of the first holder **20**A and active species **10**B in the inner space **20**B*a* of the second holder **20**B Since the openings **21**A and **21**B of the holders **20**A and **20**B are respectively closed by the shutters **29**A and **29**B at this time, the active species **10**A and **10**B thus generated do not reach the substrate **8**. As a result, no SiN_x film is deposited on the substrate **8**.

After the flow rates of the first and second source gases SG1 and SG2 and the temperatures of the catalyzer members **25**A and **25**B become steady, the shutters **29**A and **29**B are moved to their opening positions to open the openings **21**A and **21**B, exposing entirely the upper area of the substrate **8**. Thus, the active species **10**A and **10**B generated from the source gases SG1 and SG2 in the holders **20**A and **20**B are supplied to the surface of the substrate **8**, as shown by the oblique arrows in FIG. **6**. The active species **10**A and **10**B react with the Si of the substrate **8** to deposit SiN_x on the surface of the substrate **8**.

After a specific deposition period passes, the shutters **29**A and **29**B are moved to their closing positions, closing the openings **21**A and **21**B of the holders **20**A and **20**B. Thus, a desired SiN_x film (not shown) with a desired thickness is formed on the surface of the Si substrate **8**.

Then, the introduction or supply of the first and second source gases SG1 and SG2 and the heating of the first and second catalyzer members **25**A and **25**B are stopped. The unreacted source gasses SG1 and SG2 existing in the chamber **1** and other gaseous substances produced by the CVD reaction are exhausted through the gas outlet tube **14**. Thereafter, the substrate **8** with the deposited SiN_x film is taken out of the reaction chamber **1**.

Subsequently, a cleaning process is conducted to clean the inside of the chamber **1** by using the cleaning device **5** while the openings **21**A and **21**B of the catalyzer holders **20**A and **20**B are respectively closed by the shutters **29**A and **29**B in the same way as that of the first embodiment Thus, the unwanted SiN_x films deposited on the inner walls of the chamber **1**, the shutters **29**A and **29**B, and the substrate stage **9**, or the like are removed by the etching action of CF_4 or CHF_3 plasma generated by the ECR plasma generator in the cleaning device **5**. The cleaning process is conducted in a specific time period.

Through the above-described CVD process of the SiN_x film and the cleaning process of the chamber **1**, one cycle of the SiN_x film formation is completed. A same CVD process and a same cleaning process are then repeated in the same chamber **1** in the same way as described above as necessary.

With the catalytic CVD apparatus according to the second embodiment of the present invention, as shown in FIG. **6**, the source gases SG1 and SG2 (i.e., SiH_4 and NH_3) having different decomposition rates are respectively introduced into the inner spaces **20**A*s* and **20**B*a* of the holder **20**A and **20**B through the dedicated tubes **27**A and **27**B. Therefore, there is an additional advantage hat the ratio of Si and N can be accurately controlled to be stoichiometric (i.e., Si:N=3:4), thereby forming stably a stoichiometric silicon nitride film (i.e., Si_3N_4). because of the same reason as above, the first Moreover, and second source gases SG1 and SG2 can be used effectively. This means that part of the introduced source gases SG1 and SG2 is not left unreacted in the chamber **1** after the CVD process is completed. As a result, the utilization rate of the source gases SG1 and SG2 is improved. For example, the necessary amounts of the SiH_4 and NH_3 gases are decreased to approximately one-fiftieth (1/50) of that for the prior-art CVD apparatus.

If SiH_4 and NH_3 gases are introduced through a common tube into the reaction chamber **1**, as shown in the first embodiment of FIG. **4**, there arises a disadvantage that some of the introduced NH_3 gas tends to be exhausted unreacted. This is because the flow rates of the SiH_4 and NH_3 gases need to be set as approximately 1:100. Also, to treat a large amount of the unreacted NH_3 gas, there is a disadvantage that a large-sized gas treatment system is required. However, these two disadvantages can be solved in the CVD apparatus according to the second embodiment.

As described above, the apparatus according to the second embodiment has not only the same advantages as those in the first embodiment of FIG. **4** but also an additional advantage that the utilization rate of the different source gases is improved.

In the apparatus according to the second embodiment, two catalyzer holders with catalyzer members and two shutters are provided in the reaction chamber. However, it is needless to say that three or more catalyzer holders and three or more shutters may be provided in the reaction chamber according to the necessity.

THIRD EMBODIMENT

FIGS. **7** and **8** show the configuration of a CVD apparatus according to a third embodiment of the present invention,

which has the same configuration as that of the first embodiment of FIG. 4 except that a circular plate-shaped grid member **32** is additionally provided at the opening **3** of the catalyzer holder **2**. The grid member **32** is made of heat-resistant, electrically insulating material such as ceramic and is used to suppress the effect of the radiated heat from the catalyzer member **6** to the substrate **8**. Therefore, the explanation about the same configuration is omitted here for the sake of simplification by attaching the same reference symbols as those used in FIG. 4 to the same or equivalent elements in FIGS. 7 and 8.

As shown in FIG. 7, the grid member **32** is fitted into the opening **3** of the cylindrical catalyzer holder **2**. Therefore, the member **32** is entirely located in the catalyzer holder **2** when the shutter **4** closes the opening **3**. The member **32** has a plurality of penetrating holes **31** allowing the active species **10** generated in the inner space **2***a* of the holder **2** to travel to the vicinity of the substrate **8** on the stage **9**. As clearly shown in FIG. 8, each of the holes **31** has a specific aspect ratio (b/a) where b is the length of the hole **31** and a is the diameter thereof. The aspect ratio (b/a) is determined to be large enough for the rays **33** of the radiated heat from the catalyzer member **6** not to reach directly the substrate **8** on the stage **9** through any of the holes **31**.

The CVD or film formation method and the cleaning method conducted in the CVD apparatus according to the third embodiment of FIG. 7 are the same as those in the first embodiment of FIG. 4.

With the apparatus according to the third embodiment, in addition to the same advantages as those in the first embodiment of FIG. 4, there is an additional advantage that the temperature rise of the substrate **8** can be prevented during the CVD process. This is because the effect of the radiated heat from the catalyzer member **6** is suppressed by the grid member **32**.

FOURTH EMBODIMENT

FIG. **9** shows the configuration of a CVD apparatus according to a fourth embodiment of the present invention, which has the same configuration as that of the first embodiment of FIG. 4 except that a circular plate-shaped grid member **36** is additionally provided in the vicinity of the opening **3** of the catalyzer holder **2**. The grid member **36** is made of heat-resistant, electrically insulating material such as ceramic and is used to suppress the effect of the radiated heat from the catalyzer member **6** to the substrate **8**. Therefore, the explanation about the same configuration is omitted here for the sake of simplification by attaching the same reference symbols as those used in FIG. 4 to the same or equivalent elements in FIG. 9.

As seen from FIG. 9, the grid member **36** has the same structure as that of the grid member **32** provided in the third embodiment of FIG. 7. Specifically, the member **36** has a plurality of penetrating holes **35** allowing the active species **10** generated in the inner space **2***a* of the holder **2** to travel to the vicinity of the substrate **8** on the stage **9**. Each of the holes **35** has a specific aspect ratio (b/a) where b is the length of the hole **35** and a is the diameter thereof, as shown in FIG. **8**. The aspect ratio (b/a) is determined to be large enough for the rays **33** of the radiated heat from the catalyzer member **6** not to reach directly the substrate **8** on the stage **9** through any of the holes **35**.

In the apparatus according to the third embodiment of FIG. 7, the grid member **32** is entirely positioned in the catalyzer holder **2** when the shutter **4** closes the opening **3** of the holder **2**. unlike this, in the apparatus according to the fourth embodiment of FIG. **9**, the entire grid member **36** is positioned outside the catalyzer holder **2**. When the shutter **4** closes the opening **3** of the holder **2**, the member **36** is placed between the shutter **4** and the substrate **8**.

The film-formation method and the cleaning method conducted in the CVD apparatus according to the fourth embodiment are the same as those i n the first embodiment.

With the apparatus according to the fourth embodiment of FIG. **9**, in addition to the same advantages as those in the first embodiment of FIG. **4**, there is an additional advantage that the temperature rise of the substrate **8** can be prevented during the CVD process because the effect of the radiated heat from the catalyzer member **6** is suppressed by the grid member **36**.

Moreover, there is a further additional advantage that the deposition rate of the film on the substrate **8** can be prevented from lowering, the reason of which is as follows:

Due to repetition of the CVD or film-formation process, the film is deposited not only on the substrate **8** but also on the grid member **36**. As a result, after repetition of the CVD process, the penetrating holes **35** of the grid member **36** tend to be narrowed or blocked. Since the active species **10** generated in the inner space **2***a* of the catalyzer holder **2** travel to the substrate **8** through the holes **35**, the narrowing or blocking of the holes **35** reduces the deposition rate. Unlike this, in the apparatus according to the fourth embodiment of FIG. **9**, the deposited film on the member **36** can be removed during the cleaning process of the inside of the reaction chamber **1** and therefore, the deposition rate of the film on the substrate **8** can be prevented from lowering without any dedicated cleaning process for the grid member **36**

FIFTH EMBODIMENT

FIG. **10** shows the configuration of a CVD apparatus according to a fifth embodiment of the present invention, which has the same configuration as that of the fourth embodiment of FIG. **9** except that the grid member **36** is electrically connected to a power supply **37** provided outside the chamber **1**. Therefore, the explanation about the same configuration is omitted here for the sake of simplification by attaching the same reference symbols as those used in FIG. **9** to the same or equivalent elements in FIG. **10**.

As seen from FIG. **10**, the grid member **36** is designed to be applied with a negative bias voltage from the power supply **37**. Therefore, the amount or thickness of the deposited film on the grid member **36** is decreased, the reason of which is as follows;

The introduced gaseous SiF_4 and NH_3 are decomposed by the catalysis of the catalyzer member **6** fixed in the inner space **2** of the catalyzer holder **2**, thereby producing anions such as SiH_3^- and/or SiH_2^-. These anions do not attach to the member **36** because of the applied negative bias voltage to the grid member **36**, which decreases the thickness of the undesired SiN_x film deposited on the member **36**. As a result, the penetrating holes **35** of the member **36** are difficult to be narrowed or blocked compared with the apparatus according to the fourth embodiment of FIG. **9**.

With the apparatus according to the fifth embodiment of FIG. **10**, in addition to the same advantages as those in the fourth embodiment of FIG. **9**, there is an additional advantage that the amount or thickness of the deposited film on the grid member **36** is decreased.

SIXTH EMBODIMENT

FIG. **11** shows the configuration of a CVD apparatus according to a sixth embodiment of the present invention, which has the same configuration as that of the first embodiment of FIG. 4 except that a catalyzer holder **41** having a cooling device **40** is provided instead of the catalyzer holder **2**. Therefore, the explanation about the same configuration is omitted here for the sake of simplification by attaching the

same reference symbols as those used in FIG. 4 to the same or equivalent elements in FIG. 11.

As seen from FIG. 11, cooling paths 44 are formed in the walls of the catalyzer holder 41. The paths 44 communicate with the cooling device 40 provided outside the reaction chamber 1. Due to the operation of the cooling device 40, a cooling medium (not shown) is circulated through the paths 44. As the cooling medium, any liquid such as cold water and propylene glycol, or any gas such as the atmospheric air may be used.

Since the catalyzer holder 41 can be cooled by circulating the cooling medium through the paths 44 in the holder 41, the effect of the radiated heat from the catalyzer member 6 to the temperature of the substrate 8 can be suppressed effectively. Thus, the quality of the deposited film on the substrate 8 is more controllable.

As described above, with the apparatus according to the sixth embodiment of FIG. 11, in addition to the same advantages as those in the first embodiment of FIG. 4, there is an additional advantage that the quality of the deposited film on the substrate 8 is more controllable.

VARIATION

In the above-described first to sixth embodiments, the catalyzer member is made of W. However, any other refractory metal such as tantalum (Ta), titanium (Ti), and molybdenum (Mo), or any other material than refractory metals may be used.

Any other type of plasma generator than the ECR plasma generator may be used for the cleaning device 5. For example, a plasma generator with the remote plasma configuration, in which a plasma generator is provided outside the reaction chamber 1 and the generated plasma in the generator is sent to the inside of the chamber 1, may be used. An optically-excited plasma generator may be used. The parallel-plate or barrel type electrodes may be used. The inductively coupled plasma (ICP) configuration may be used.

In the above-described first to sixth embodiments, SiH_4 and NH_3 gases are used as the source gases for forming a SiN_x film on the substrate 8 However, disilane (Si_2H_6) and nitrogen (N_2) gases may be used as the source gases.

Moreover, any other dielectric or conductive film than SiN_x may be formed on the substrate 8 by suitably selecting the source gas or gases. As the dielectric film, any film made of SiO_2 or alumina (Al_2O_3) may be used. As the conductive film, any film made of polysilicon or amorphous silicon may be used.

For example, if only monosilan (SiH_4) gas is used as the source gas, a polysilicon film is formed on the substrate 8 If oxygen (O_2) gas is added to the mixture of SiH_4 and NH_3 gases, a silicon oxynitride (SiO_xN_y) film may be formed on the substrate 8. Furthermore, if only hydrogen (H_2) gas is used as the source gas, the surface of the substrate 8 can be cleaned by using hydrogen radicals. Thereafter, the film deposition method used in any one of the first to sixth embodiments may be carried out.

Any other substrate than single-crystal Si (e.g., ceramic substrate) may be used as necessary.

The above-described deposition conditions relating to the temperature, pressure, and flow rate are simply shown as examples. Therefore, they may be changed according to the purpose or application.

While the preferred forms of the present invention have been described, it is to be understood that modifications will be apparent to those skilled in the art without departing from the spirit of the invention. The scope of the invention, therefore, is to be determined solely by the following claims.

What is claimed is:

1. A CVD apparatus comprising:

a reaction chamber;

a substrate stage located in said chamber, a substrate being placed on said stage;

a catalyzer holder located in said chamber for holding a catalyzer member;

said holder having an inner space in which said catalyzer member is fixed;

said holder having an opening that communicates with said inner space and that faces toward said substrate placed on said stage;

a shutter located in said chamber for closing said opening of said holder;

a cleaning device for cleaning an inside of said chamber after a CVD process is completed; and

a gas supply line for supplying a source gas into said inner space of said holder;

wherein when a film is formed on said substrate, said source gas is supplied into said inner space of said catalyzer holder to generate an active species due to a catalysis of said catalyzer member, and said active species is supplied to said substrate placed on said stage through said opening of said catalyzer holder;

and wherein when the inside of said chamber is cleaned by said cleaning device, said substrate is taken out of said chamber and said opening of said holder is closed by said shutter, separating said catalyzer member located in said holder from an outside atmosphere of said holder.

2. The apparatus as claimed in claim 1, further comprising:

an additional catalyzer holder located in said chamber for holding an additional catalyzer member; and

an additional shutter located in said chamber for closing an opening of said additional holder;

wherein said additional holder has an inner space in which said additional catalyzer member is fixed;

and wherein said opening of said additional holder communicates with said inner space of said additional holder and that faces toward said substrate placed on said stage.

3. The apparatus as claimed in claim 1, further comprising a grid member having penetrating holes for allowing said active species to reach said substrate placed on said stage.

4. The apparatus as claimed in claim 3, wherein said grid member is located inside said holder, and said grid member is separated from said outside atmosphere of said holder when said shutter closes said opening of said holder.

5. The apparatus as claimed in claim 3, wherein said grid member is located outside said holder, and said grid member is not separated from said outside atmosphere of said holder even when said shutter closes said opening of said holder.

6. The apparatus as claimed in claim 3, wherein said grid member is designed for being applied with a negative bias voltage.

7. The apparatus as claimed in claim 1, wherein said holder includes a path for allowing a cooling medium to flow through a wall of said holder.

8. The apparatus as claimed in claim 1, wherein said gas supply line is communicated with an upper part of said catalyzer holder, and said source gas supplied into said inner space of said holder flows downward to be contacted with said catalyzer member.

* * * * *

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United States Patent [19]

Mitro et al.

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[45] Date of Patent: Jul. 13, 1999

[54] APPARATUS FOR ETCHING AND COATING SAMPLE SPECIMENS FOR MICROSCOPIC ANALYSIS

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[73] Assignee: **Gatan, Inc.**, Pleasanton, Calif.

[21] Appl. No.: **08/954,080**

[22] Filed: **Oct. 20, 1997**

Related U.S. Application Data

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[51] **Int. Cl.**^{6} **C23C 14/34**

[52] **U.S. Cl.** **204/298.04**; 204/192.11; 204/298.36; 204/192.34

[58] **Field of Search** 204/298.04, 192.11, 204/298.36, 192.34, 298.12, 192.12, 192.15, 192.26, 298.28

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Attorney, Agent, or Firm—Killworth, Gottman, Hagan & Schaeff, LLP

[57] **ABSTRACT**

An apparatus and process for the etching and coating of samples in a single vacuum chamber, thus minimizing handling and transfer of the samples is provided. The apparatus includes a sealed chamber and a vacuum pump for forming and maintaining a vacuum in the chamber, a first ion gun positioned in the chamber to etch a sample, a sputtering target in the chamber, and at least one additional ion gun positioned in the chamber to cause material from the target to be directed onto the sample.

14 Claims, 5 Drawing Sheets

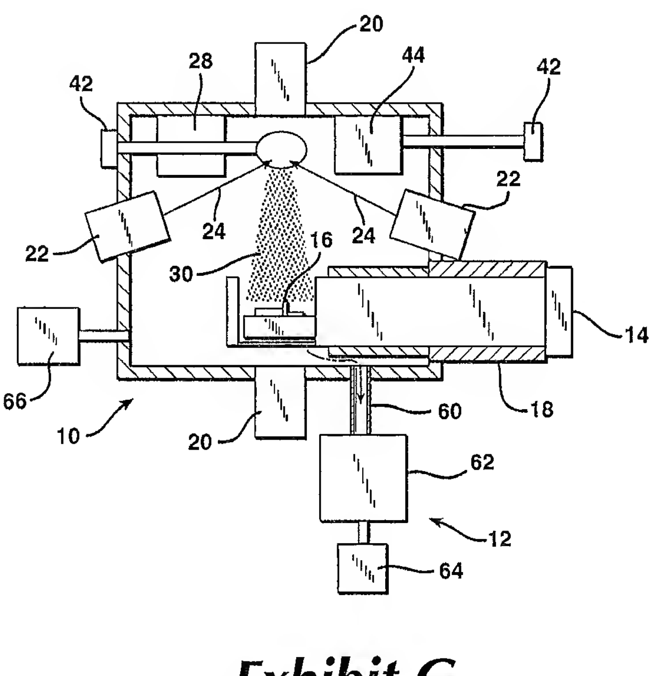


Exhibit G

FIG. 1

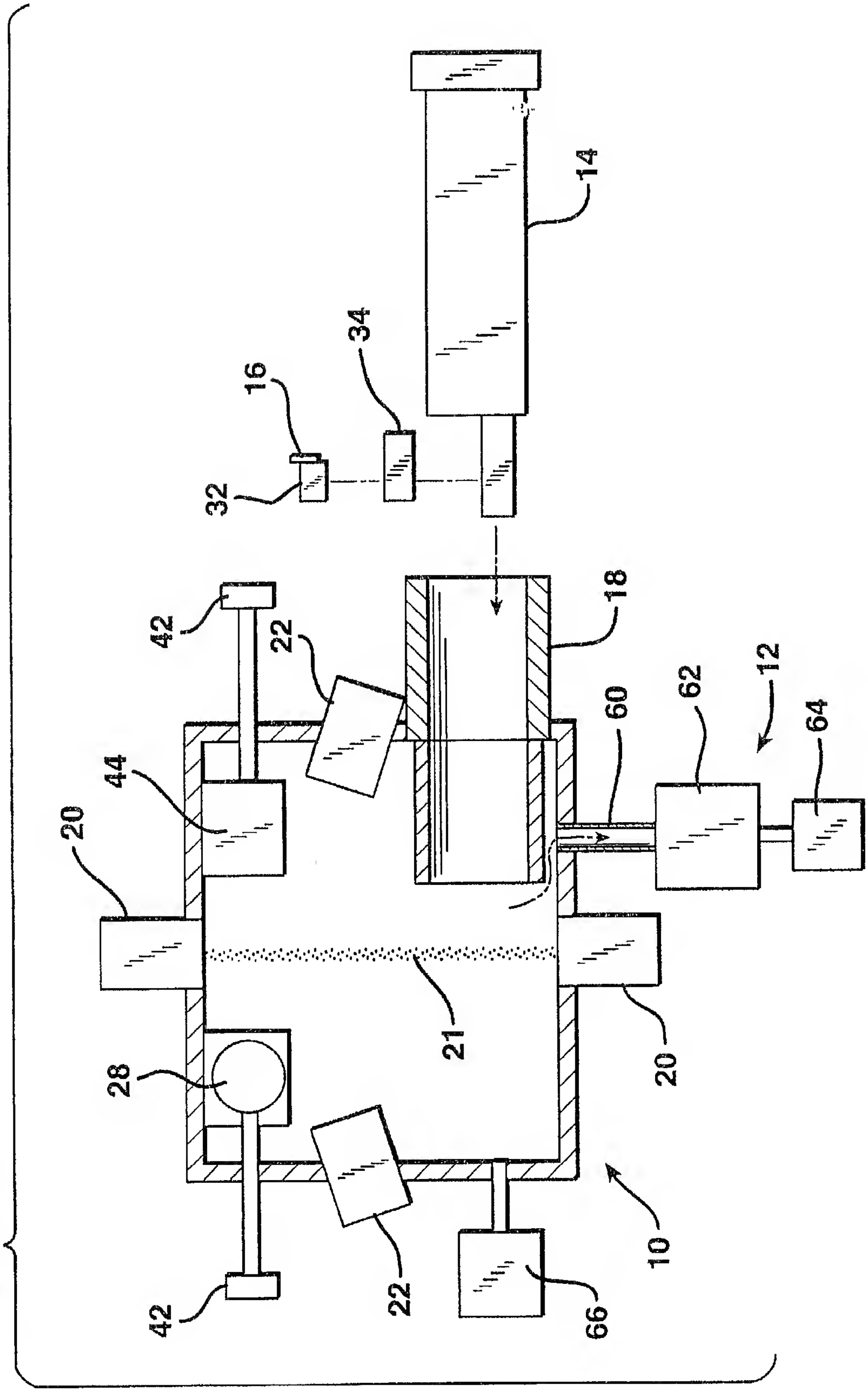


FIG. 2

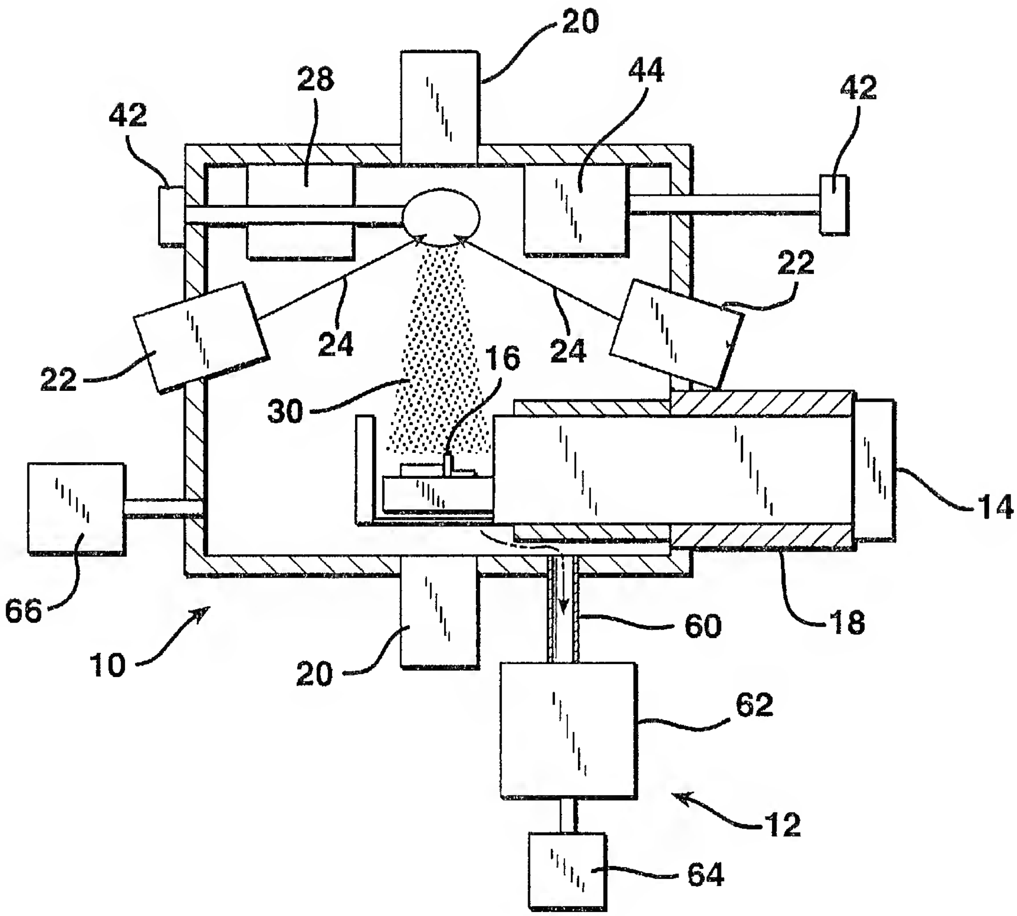
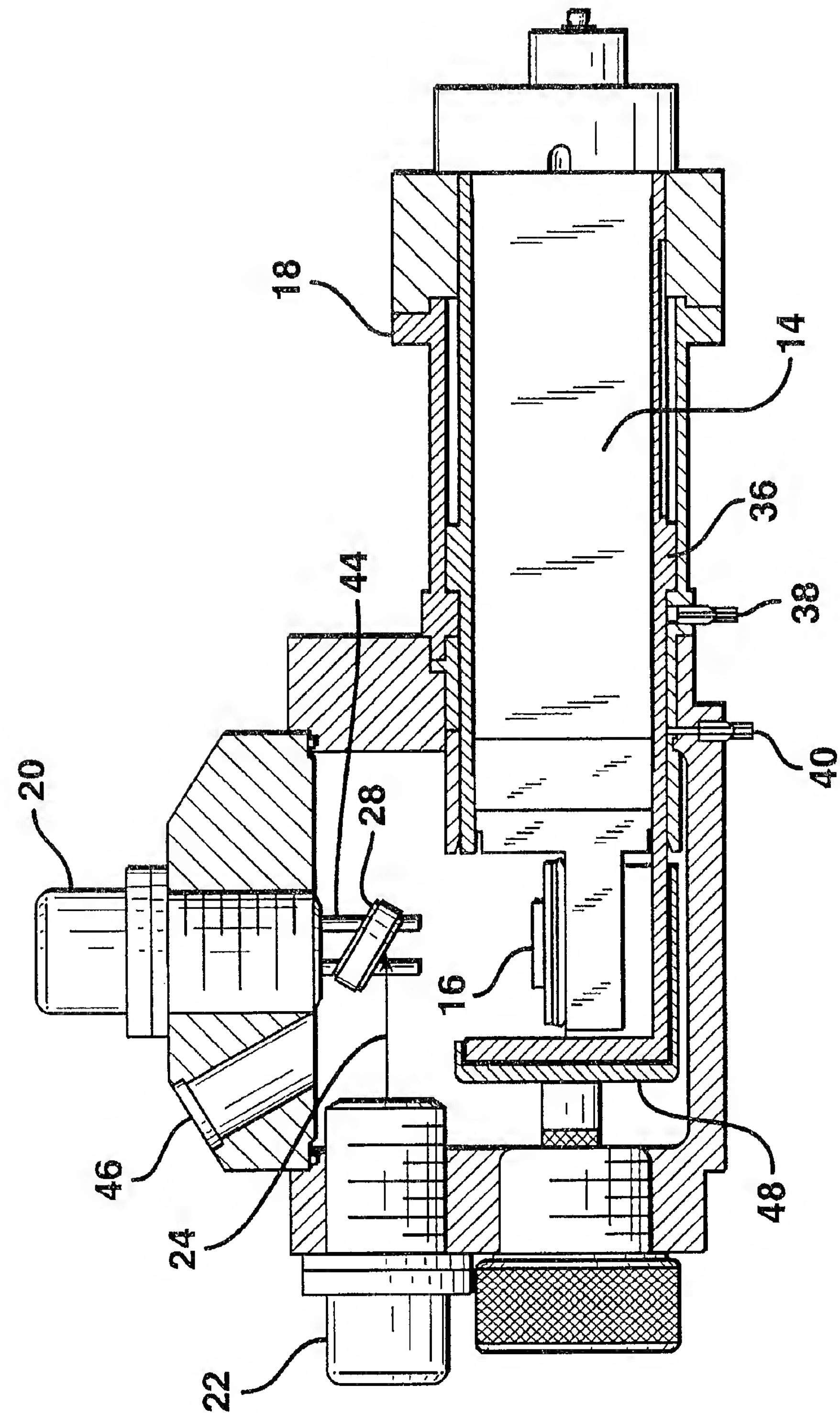


FIG. 3



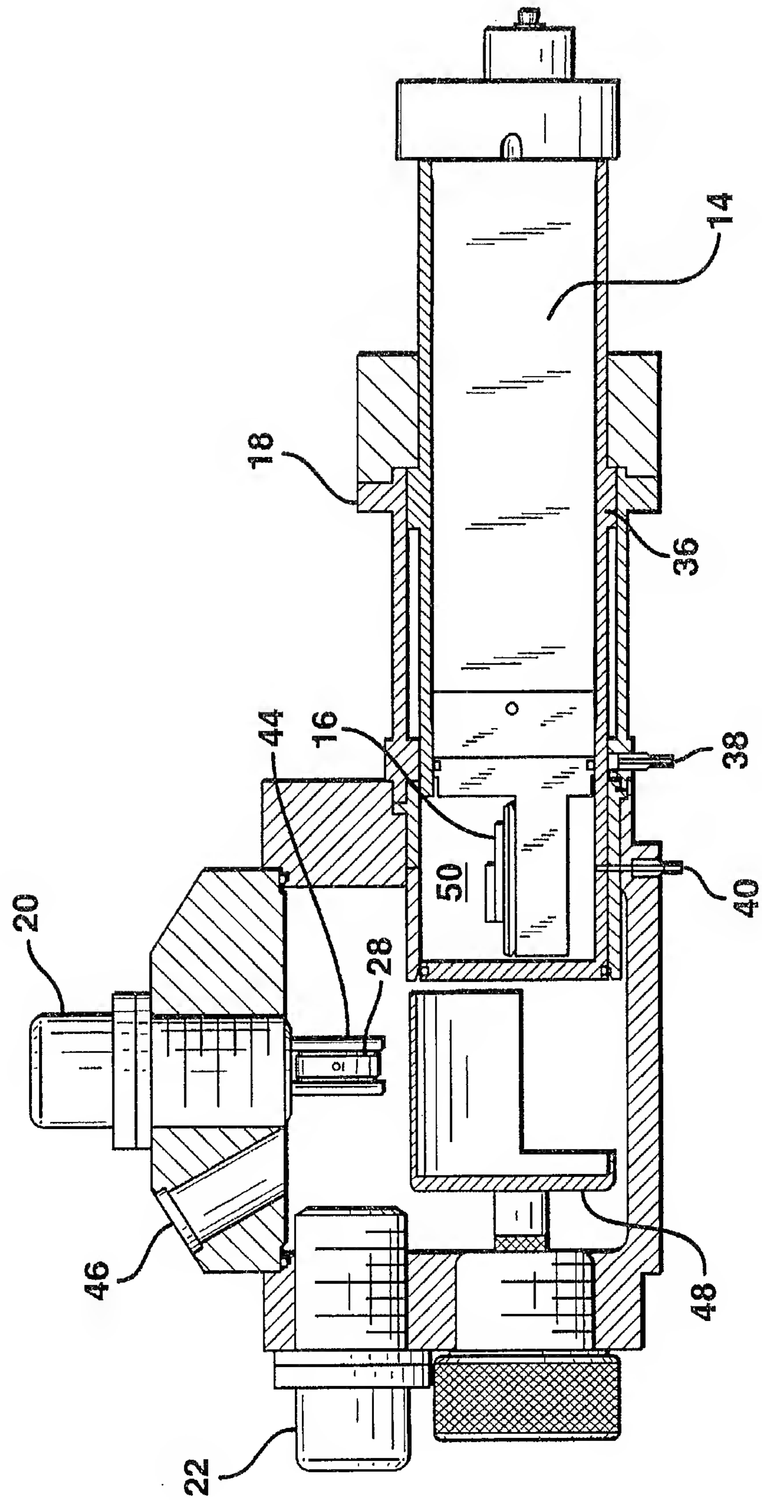


FIG. 4

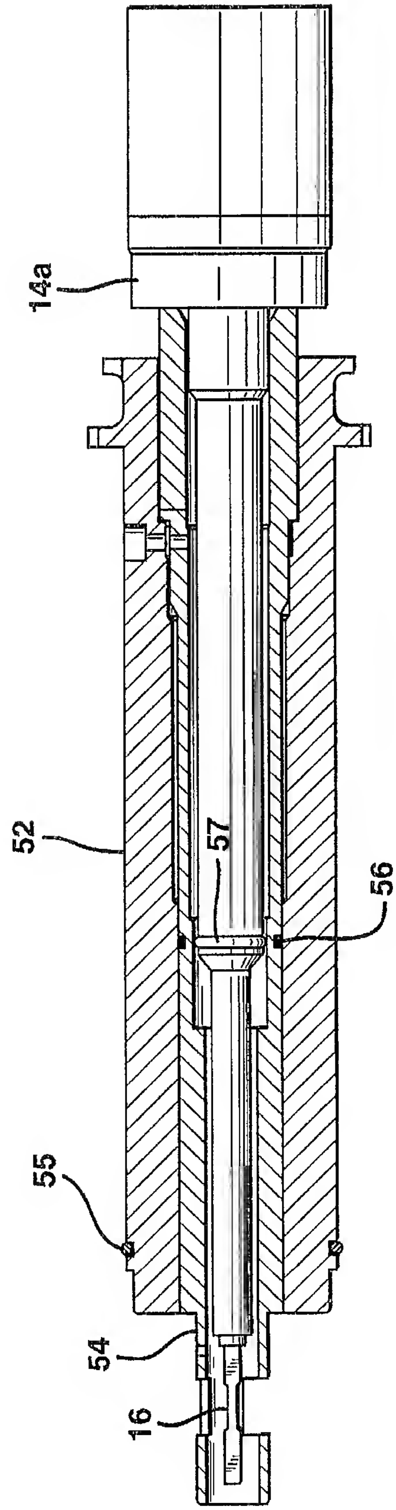


FIG. 5

APPARATUS FOR ETCHING AND COATING SAMPLE SPECIMENS FOR MICROSCOPIC ANALYSIS

CROSS REFERENCE TO RELATED APPLICATIONS

This patent application claims the benefit of U.S. Provisional Application Serial No. 60/033,495, filed Dec. 20, 1996.

BACKGROUND OF THE INVENTION

The present invention relates to an apparatus for both etching and coating a specimen prior to analysis, and more particularly to an ion beam etching and sputter coating system for the preparation of sample specimens to be analyzed in a microscope.

Ion milling systems are used extensively for etching, milling, cutting, and cleaning samples of various materials such as ceramics, semiconductors, metals, and combinations thereof to make possible and/or enhance certain features for analysis in a microscope, typically analysis with an electron or optical microscope. Many of these samples, particularly samples of electrically insulating materials, are coated after cleaning or etching and prior to examination in an electron or optical microscope to prevent charging effects. Certain coatings also have the effect of increasing the secondary electron yield from almost all types of material.

Typically for etching and coating, the samples to be studied are first mounted to a sample holder for the purpose of mechanically polishing one or more surfaces until such surfaces are flat, parallel, and scratch free. The polished sample is then removed from the polishing holder, mounted to a second holder, and placed into an ion milling device for etching. In the ion mill, the sample is positioned in the path of one or more ion beams and etched at a relatively steep angle between the incident beam(s) and the sample surface.

Once etching has been completed, the sample may require remounting to a third holder to enable installation into a separate device for the purpose of depositing a conductive coating thereon. Previously, such coatings were applied by such techniques as thermal evaporation, arc discharge, and diode, magnetron, or RF sputtering. More recently, the coatings have been applied by sputter coating in a vacuum using ion beam techniques.

After coating, the sample may be mounted to a final stub or holder designed for use in a specific microscope, for example a transmission electron microscope, a scanning electron microscope, or even a light microscope. Thus, the current techniques for sample preparation require that the samples be handled multiple times and transferred among several instruments and vacuum systems. These techniques expose the samples to potential damage and/or contamination of the sample surface.

Accordingly, there is a need in the art for a process and system which minimizes sample handling and exposure to potential damage and/or contamination.

SUMMARY OF THE INVENTION

The present invention meets that need by providing for the etching and coating of samples in a single vacuum chamber, thus minimizing handling and transfer of the samples. In accordance with one aspect of the invention, an apparatus for the precision etching and coating of a sample is provided and includes a sealed chamber and a vacuum system for forming and maintaining a vacuum in the chamber. The apparatus also includes a sample holder and an airlock for moving samples quickly into and out of the chamber.

An ion milling gun is positioned in the chamber to direct a stream of ions, neutrals, or combinations thereof onto the sample to etch the sample. Also in the chamber, at least one movable sputtering target is positioned for coating purposes. The target is shielded from the ion and neutrals stream emanating from the milling gun during etching. To coat the sample, at least one additional ion gun is positioned to direct a stream of ions and neutrals onto the target. After etching of the sample, the target is moved into a position in the chamber where material sputtered from it becomes coated onto the sample.

In a preferred embodiment, there are two ion guns positioned to direct streams of ions and neutrals from different angles to impact the target and sputter deposit material from the target onto the sample. The moveable target may be positioned to aid in efficiently directing sputtered material onto the sample.

In accordance with another aspect of the invention, a process is provided for the etching and sputter coating a sample in a single evacuated chamber without the need to remove the sample or break the vacuum during processing. The process includes the steps of mounting the sample onto a sample holder and then loading the sample and holder into the evacuated chamber. The sample is etched using an ion milling gun. Then, the sample may be immediately coated in the same chamber without any need for further handling or transfer using a target material and additional sputtering ion gun or guns which are provided in the chamber.

After moving the target into position, the ion gun or guns are energized and produce energetic ions and neutrals which impinge onto the target and cause target material to be sputter deposited onto the sample. The coated sample may then be removed from the chamber. With the airlock, there is no need to continually cycle the pressure in the chamber from atmospheric to vacuum and back. Rather, the vacuum need be formed only once and then maintained.

By performing the etching and coating operations in the same chamber, the sample is not moved or handled between process steps, which minimizes the amount of contaminants to which the sample may be exposed. Further, the sample may be initially mounted onto a sample holder and then supported by that same holder throughout the entire etching/coating process. The same holder may even be used to support the sample for microscopic analysis.

In a preferred embodiment of the process, the sample is initially mounted onto a holder and then mechanically polished. The polished sample is then transferred into the vacuum chamber through an airlock where it is etched and then coated. The finished, coated sample is then removed from the vacuum chamber ready for viewing in a selected microscope.

The system and process of the present invention has some utility in sample preparation for scanning electron microscope (SEM) analysis, transmission electron microscope (TEM) analysis, and light microscope observations analysis. Accordingly, it is a feature of the present invention to provide for the etching and coating of samples in a single device under vacuum, thus minimizing handling and transfer of the samples. This and other features and advantages of the invention will become apparent from the following detailed description, the accompanying drawings, and the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic side view of the system of the present invention with the sample and sample holder positioned outside the chamber;

FIG. 2 is a schematic side view of the system with the sample and holder therein, and the system operating in a sputter deposit mode to coat the sample;

FIG. 3 is a side view, in partial section, illustrating the target and sample holder in position for sputter coating;

FIG. 4 is a side view, in partial section, illustrating the target and sample holder in retracted positions; and

FIG. 5 is a side view, in partial section, illustrating features of a TEM sample holder.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

With reference to FIG. 1, the etching and coating system of the present invention includes a sealed chamber **10** which is evacuated by vacuum system **12** to provide a working vacuum pressure in the chamber. A sample holder **14** is used to mount a sample **16** thereon. Sample holder **14** may be cooled, such as by for example using liquid nitrogen, to reduce or maintain the temperature of sample **16** within a predetermined range as taught by Jones et al, U.S. Pat. No. 4,950,901, the disclosure of which is hereby incorporated by reference.

Depending upon the sample and the desired type of microscopic analysis instrument, it may be desirable to polish the sample mechanically prior to insertion into vacuum chamber **10**. Commercial mechanical polishing devices are readily available and are used to grind and polish one or more of the sample surfaces until they are flat, parallel, scratch free, and of a desired thickness.

The polished sample **16**, mounted on holder **14**, is then inserted into vacuum chamber **10** through airlock **18** to position the sample beneath ion etch gun **20**. Airlock **18**, in a preferred embodiment, is pneumatically controlled to provide fast loading and unloading (i.e., 30 seconds) of the sample. By using an airlock, the vacuum chamber **10** is only vented for routine servicing, allowing the base vacuum pressure to be maintained. A pneumatically-controlled airlock is described in Swann, U.S. Pat. No. 4,272,682.

Airlock **18** may vary in size and shape and may be designed to accept various configured sample holders as in the case of etching or coating TEM samples while mounted in a TEM holder or when a probe is used for monitoring the rate of sputtered coating deposition and total coating thickness. TEM sample holders vary in size and configuration according to manufacturer. Thus, rather than manufacture separate airlocks **18** to fit each sample holder, a removable assembly may be provided into which sample holders of various preselected sizes and configurations may be inserted. Such a removable assembly comprises a reducing sleeve **52** and interchangeable adaptors **54** (only one shown), as illustrated in FIG. **5**, which enable the accommodation of TEM sample holders of all varieties.

Referring to FIG. **5**, reducing sleeve **52** has a generally cylindrical configuration and the same outer dimensions as a conventional sample holder 14 (see FIG. 1) which it replaces. Sleeve **52** also has an inner diameter sized and adapted to fit the fixed outer diameter of an interchangeable adaptor **54**. Interchangeable adaptors **54** have an inner diameter sized and adapted to accept TEM sample holders of various sizes and configurations such as sample holder **14*a*** illustrated in FIG. **5**. Thus, the reducing sleeve and adaptor assembly fits into airlock **18** as shown in FIG. **5**. O-ring **55** provides a vacuum tight seal between adaptor **54** and the inner wall of pneumatic airlock piston **36** (shown in FIGS. **3** and **4**).

O-ring **57** provides a vacuum tight seal between adaptor **54** and sleeve **52**. Sample holder **14*a*** is fitted into adaptor **54** with a vacuum tight seal being provided by O-ring **57** in sample holder **14*a***. When in position, the portion of the TEM sample holder **14*a*** which contains the sample **16** itself is extended into sealed chamber **10** (see FIG. 1) by the operation of airlock **18**. While in chamber **10** (see FIG. 1), sample **16** is exposed to the ion beam for etching or to the sputtered target material **30** for coating. Thus, a user can process TEM samples using sample holders of various manufacturers simply by interchanging adaptors **54**.

As shown in FIG. 1, sample **16** is secured to a sample mount **32**, and mount **32** is inserted into a sample adaptor **34**. The entire assembly is then inserted into sample holder **14**. As best shown in FIGS. **3** and **4**, sample holder **14** is housed in airlock **18** and is moved into and out of position by a pneumatic piston **36**. Gas pressure is provided to the piston from a source of compressed gas (not shown) connected through port **38**. Airlock vacuum is achieved by connection **40** which communicates with a vacuum pump (not shown).

Sample holder **14** may be designed to either "rock or rotate" or "rock and rotate" during the etching, cleaning, and/or coating processes. Such rocking and/or rotating mechanisms are known in this art. Rotation of the sample during etching produces a more uniformly etched sample surface and a more uniform etching rate. Rocking and rotating the sample during coating produces homogeneous coatings of uniform thickness. A fixed rock angle may be selected to change the incident angle of the ion beam on the sample surface from an angle normal to the sample surface to that of a lesser angle. The fixed angle also helps to increase the size of the etched area when combined with rotation.

Also in FIG. **1**, an ion etch gun **20** is positioned in chamber **10** as shown to provide the relative beam angle between the incident beam **21** and the sample surface. Gun **20** may be mounted at the top of chamber **10** as shown, or at the bottom, or at a location which would provide angled etching of the sample. Further, gun **20** may be positioned so as to vary the distance between the gun and the surface of the sample. That is, gun **20** may be moved inwardly or outwardly from its position on the chamber wall. Moving gun **20** closer to the sample surface has the effect of increasing the etch rate for a given gun energy (keV). Such increased etch rate is useful where the gun is used for slope cutting of a sample or TEM sample milling.

Additionally, gun **20** may be mounted such that it is able to pivot. This provides the ability to change the angle at which the energetic ions and neutrals impinge the sample surface for a fixed, horizontally oriented sample. Thus, the angle of ion impingement could be adjusted without moving the sample.

A number of ion etching or ion milling guns are readily commercially available. For example, ion gun **20** may comprise a grounded cathode and an anode connected to an adjustable high voltage supply (not shown). A gas or combination of gases, typically any noble or inert gas such as argon or xenon, may be supplied to the gun from a separate source **66**. The high voltage discharge between the anode and cathode generates and directs an energetic beam **21** of ions and neutrals towards sample **16** (when sample **16** is in the position shown in FIG. **2**). Ion etch gun **20** may also comprise a rare earth magnet Penning gun which is capable of delivering a high current density ion beam which produces a high sample etching rate, reducing etching time.

Optionally, a second ion gun **20** may be positioned on the opposite side of chamber **10** as shown. Such a second gun would be able to provide simultaneous two-sided milling of

samples for transmission electron microscopy (TEM). The ion gun or guns **20** may also be used to provide re-milling or cleanup of TEM samples which were initially prepared by broad ion beam (BIB) milling or focused ion beam (FIB) milling, or mechanically thinned using a known wedge technique. Such samples, still mounted in a TEM holder, may be thinned using one or more ion guns to mill at shallow angles.

The ion gun or guns **20** may also be used not only to clean (etch) stand-alone TEM samples but also samples mounted in a TEM sample holder, thus cleaning both the sample and holder simultaneously or cleaning the holder only. Such a cleaning improves high resolution imaging by removing amorphous layers and carbon-containing contaminants from the sample (and holder) surface by exposure to the etching beam at selected keV energies.

During etching of the sample, target or targets **28** are maintained in a shielded location (FIGS. **1** and **4**) out of the path of the ion beam. As best illustrated in FIGS. **1–2**, targets **28** are carried on the tip of a retractable piston assembly **42** and can be moved from a retracted position (FIG. **1**) out of the path of the ion gun to an extended position (FIG. **2**). When in a retracted position, targets **28** are shielded on both sides by target shields **44**. (also shown in FIGS. **3** and **4**)

As can be seen in FIGS. **1** and **2**, located on chamber **10** is a vacuum system **12** which includes a drag pump manifold **60** which is in turn connected to molecular drag pump **62**. Molecular drag pump **62** provides a suitable vacuum level for the operation of the ion guns by providing an ultimate vacuum of 10^{-6} torr in sealed chamber **10**. Molecular drag pump **62** will not operate properly unless its outlet is prepumped; therefore it is necessary to reduce its foreline or outlet vacuum. This is accomplished by backing molecular drag pump **62** with an oil free diaphragm pump **64**. The oil free system is preferred to eliminate the possibility of introducing hydrocarbon contamination from the lubricating oils of the pump into sealed chamber **10**.

As also shown in FIGS. **3** and **4**, chamber **10** may include a viewing window **46**. Window **46** provides an operator with a quick visual inspection of the working portion of vacuum chamber **10** to verify the correct operation of the device during rocking and/or rotation of the sample, the correct operation of the ion guns during etching or coating, and the correct positioning of shutter **48**. Importantly, the window also permits viewing of the sample to insure that it is properly positioned, has not slipped from its holder or mount, has not changed angle during movement of the holder or during loading or unloading through the airlock.

With reference again now to FIG. **2**, once etching of the sample is completed, ion etch gun **20** is turned off, and one of the targets **28** is moved into position. One or more ion sputter guns, such as, for example, the pair of ion sputter guns **22** are activated and direct energetic beams of ions and neutrals at the target. Ion sputter guns may operate in the same general manner as ion etch gun **20**. In a preferred embodiment of the invention, ion sputter guns **22** comprise rare earth magnet, Penning ion guns.

Penning ion guns provide a high density ion flux and operate over a broad range of ion energies. Penning ion guns are advantageous as well in that they have low maintenance requirements, with no need for replacement of parts. The sputter deposits produced from the ion guns is high quality and amorphous.

In a typical arrangement, a sample, such as a ceramic or semiconductor material, will be coated with a thin, amorphous layer of a conductive material. For example, target **28** may comprise chromium, platinum, gold-palladium, iridium, tungsten, carbon, etc. Ion beams **24** from ion guns **22** cause target material **30** to be sputter deposited onto sample **16**. The thickness of the deposited coating may be monitored using conventional techniques. Generally, the target may be sputter cleaned prior to deposition of the coating for a short initial period by exposing it to the energized stream of ions and neutrals.

As shown in greater detail in FIGS. **3** and **4**, there may be an independent rotatable shutter **48** so that the sample is protected during cleaning of the target. FIG. **3** illustrates the target in an extended working position such that the energized beam **24** contacts target **28** to sputter deposit material onto sample **16**. In FIG. **3**, rotatable shutter **48** is in an "open" position to expose the sample for coating.

Referring now to FIG. **4**, target **28** is shown in a retracted, shielded position as it would be during the etching procedure, and shutter **48** has been rotated to a "closed" position which can also be used to isolate the sample. Shutter **48** preferably comprises an electrically conductive material such as a metal which permits it to act as a Faraday cup or cage. By suitable connections (not shown), shutter **48** may also be used to monitor the ion current from first ion gun **20**. Also, for purposes of understanding and illustration, the sample holder is shown in a retracted position within airlock chamber **50**, and shutter **48** has been rotated to a "closed" position.

Referring to FIG. **1**, once a desired coating thickness is attained, the ion guns are turned off, and the sample is removed from chamber **10** through airlock **18**. As the sample is already mounted on a suitable stub or mount **32**, the sample may be loaded into or taken directly to a desired microscope for analysis. The apparatus and process of the present invention provide a technique which reduces sample handling and transfer to a minimum number of steps and substantially reduces the possibility of sample damage.

The precision etching and coating system of the present invention may be used for ion beam slope cutting of samples. This is accomplished by using ion gun **20** and fixing the angle of a screened-mount sample holder to cross cut sections through heterogeneous solids such as, for example, integrated circuits and various semiconductor electronic devices. The screen which is mounted onto the sample holder comprises, for example, a block of metal having one or more sharply-defined knife edges. The metal of the screen serves as a protective mask for portions of the sample, while exposed areas of the sample are etched away. This provides the ability to investigate the cross-sectional microstructure of a device to reveal regions deep inside of the material for SEM observations and microanalysis. Once sufficiently etched, the sample is immediately sputter coated in chamber **10** with a desired target material using ion guns **22**.

The system of the present invention may also be used to wire shadow a TEM sample by cross sectioning the sample without glue line preparation. Again, once sufficiently etched, the sample is immediately sputter coated in chamber **10**. While both beam slope cutting and wire shadowing are known techniques, the present system permits the etched and cut samples to be immediately sputter coated in the same vacuum chamber without needing to move the samples.

The precision etching and coating system may also be used with chemical etching processes using non-inert gases such as reactive ion beam etching (RIBE) and chemically-assisted ion beam etching (CAIBE). In this embodiment, such non-inert gases, and combinations thereof, may be supplied to chamber **10** through an external source such as

source 66 (as shown in FIGS. 1 and 2). Halogens and halogen-containing gases as well as oxidants such as oxygen and oxygen-containing gases and combinations of such gases including I_2, Cl_2, Br_2, N_2O_4, CF_4/O_2, etc. produce superior results for special materials used in the semiconductor industry. After etching, either by RIBE or CAIBE, the sample may be immediately sputter coated using the target material and ion guns 22.

The system of the present invention may also be used to sputter coat metallographic samples for micro-hardness tests and light microscope applications.

While certain representative embodiments and details have been shown for purposes of illustrating the invention, it will be apparent to those skilled in the art that various changes in the methods and apparatus disclosed herein may be made without departing from the scope of the invention, as defined by the accompanying claims.

We claim:

1. An apparatus for the precision etching and coating of a sample for microscopic analysis comprising: a chamber communicating with a source of vacuum to form and maintain a vacuum in said chamber; a sample holder; an airlock in said chamber through which said sample holder is loaded and removed; a first ion gun positioned in said chamber to etch a sample mounted on said sample holder; a sputtering target in said chamber and a shield in said chamber for shielding said sputtering target; and at least one additional ion gun positioned in said chamber to cause material from said target to be directed onto said sample, said sputtering target being movable from a first shielded position out of a path of a stream of ions and neutrals emanating from said at least one additional ion gun to a second position in the path of said stream.

2. An apparatus as claimed in claim 1 in which said sample holder is cooled to reduce or maintain a temperature of said sample within a predetermined range.

3. An apparatus as claimed in claim 1 including a viewing window in said chamber.

4. An apparatus as claimed in claim 1 in which said first ion gun is adjustable to vary a distance between said ion gun and a surface of said sample.

5. An apparatus as claimed in claim 1 in which said first ion gun is pivoted to alter an angle of impact of a stream of ions and neutrals onto a surface of said sample.

6. An apparatus as claimed in claim 1 in which each of said sputtering targets is mounted to a retractable piston assembly.

7. An apparatus as claimed in claim 1 including a shutter in said chamber movable from a first position shielding said sample to a second position out of a path of a stream of ions and neutrals emanating from said first ion gun.

8. An apparatus as claimed in claim 7 in which said shutter comprises an electrically conductive material which acts as a Faraday cup.

9. An apparatus as claimed in claim 8 in which an ion current from said first ion gun is monitored by said shutter.

10. An apparatus as claimed in claim 1 in which said source of vacuum comprises an oil-free vacuum system including a molecular drag pump in combination with a diaphragm pump.

11. An apparatus as claimed in claim 1 further comprising a removable assembly which, in conjunction with said airlock, permits insertion and removal of sample holders of preselected sizes and configurations.

12. An apparatus as claimed in claim 11 in which said removable assembly comprises a generally cylindrical reducing sleeve and a generally cylindrical interchangeable adaptor, said reducing sleeve having an inner diameter sized and adapted to fit the outer diameter of said generally cylindrical interchangeable adaptor.

13. An apparatus as claimed in claim 12 in which said generally cylindrical interchangeable adaptor has an inner diameter which is sized and adapted to fit said sample holders.

14. An apparatus as claimed in claim 1 in which said sample holder includes a screened mount thereon, said screened mount comprising a block having one or more sharply-defined edges.

* * * * *

US006419802B1

(12) **United States Patent**
Baldwin et al.

(10) **Patent No.: US 6,419,802 B1**
(45) **Date of Patent: Jul. 16, 2002**

(54) **SYSTEM AND METHOD FOR CONTROLLING DEPOSITION THICKNESS BY SYNCHRONOUSLY VARYING A SPUTTERING RATE OF A TARGET WITH RESPECT TO A POSITION OF A ROTATING SUBSTRATE**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/810,720**

(22) Filed: **Mar. 16, 2001**

(51) **Int. Cl.**[7] **C23C 14/34**; C23C 16/00; B05C 11/00

(52) **U.S. Cl.** **204/192.13**; 204/298.03; 204/298.08; 204/298.28; 427/9; 427/255.5; 118/712; 118/665; 118/669; 118/715; 118/730

(58) **Field of Search** 204/298.03, 298.08, 204/298.28, 192.13; 118/712, 665, 669, 715, 730; 427/9, 255.5

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6,197,164 B1	*	3/2001	Pinarbasi	204/192.11

* cited by examiner

Primary Examiner—Steven H. VerSteeg
(74) *Attorney, Agent, or Firm*—Morgan, Lewis & Bockius LLP

(57) **ABSTRACT**

A system and method for controlling a circumferential deposition thickness distribution on a substrate includes a motor that rotates the substrate and a position sensor that senses a position of the substrate. At least one deposition thickness sensor senses the deposition thickness of the substrate at multiple positions on a circumference of a circle centered about an axis of rotation of the substrate. At least one controller drives a vapor source used to emit material for a deposition on a substrate. The at least one controller is coupled to the position sensor and the deposition thickness sensor. The controller synchronously varies an emission rate of material from the vapor source with respect to the position of the substrate to control the circumferential deposition thickness distribution.

13 Claims, 9 Drawing Sheets

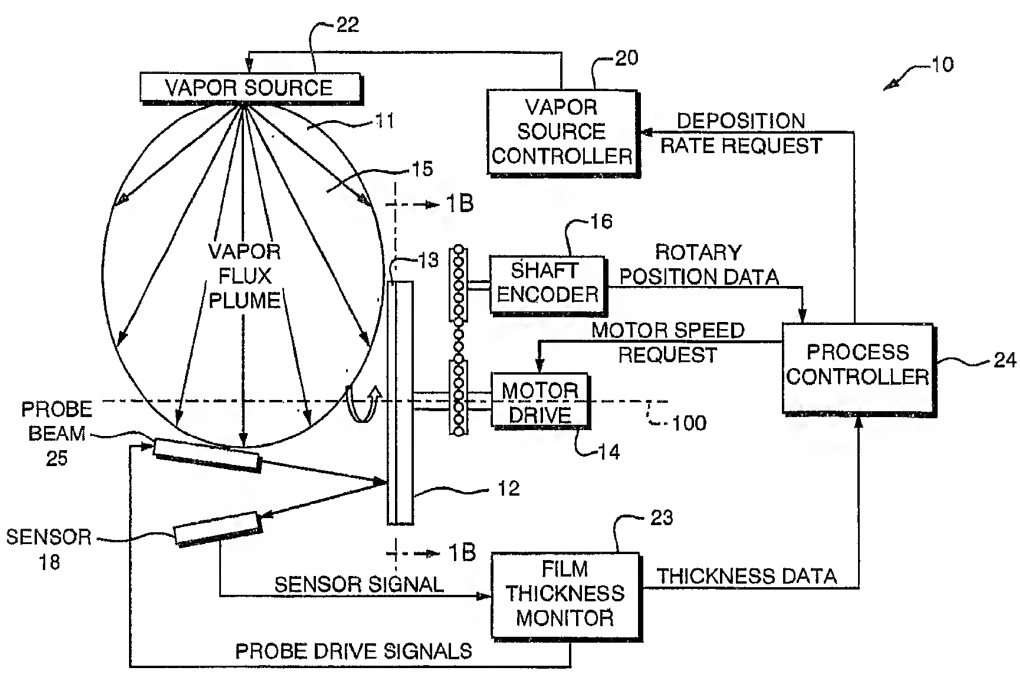


Exhibit H

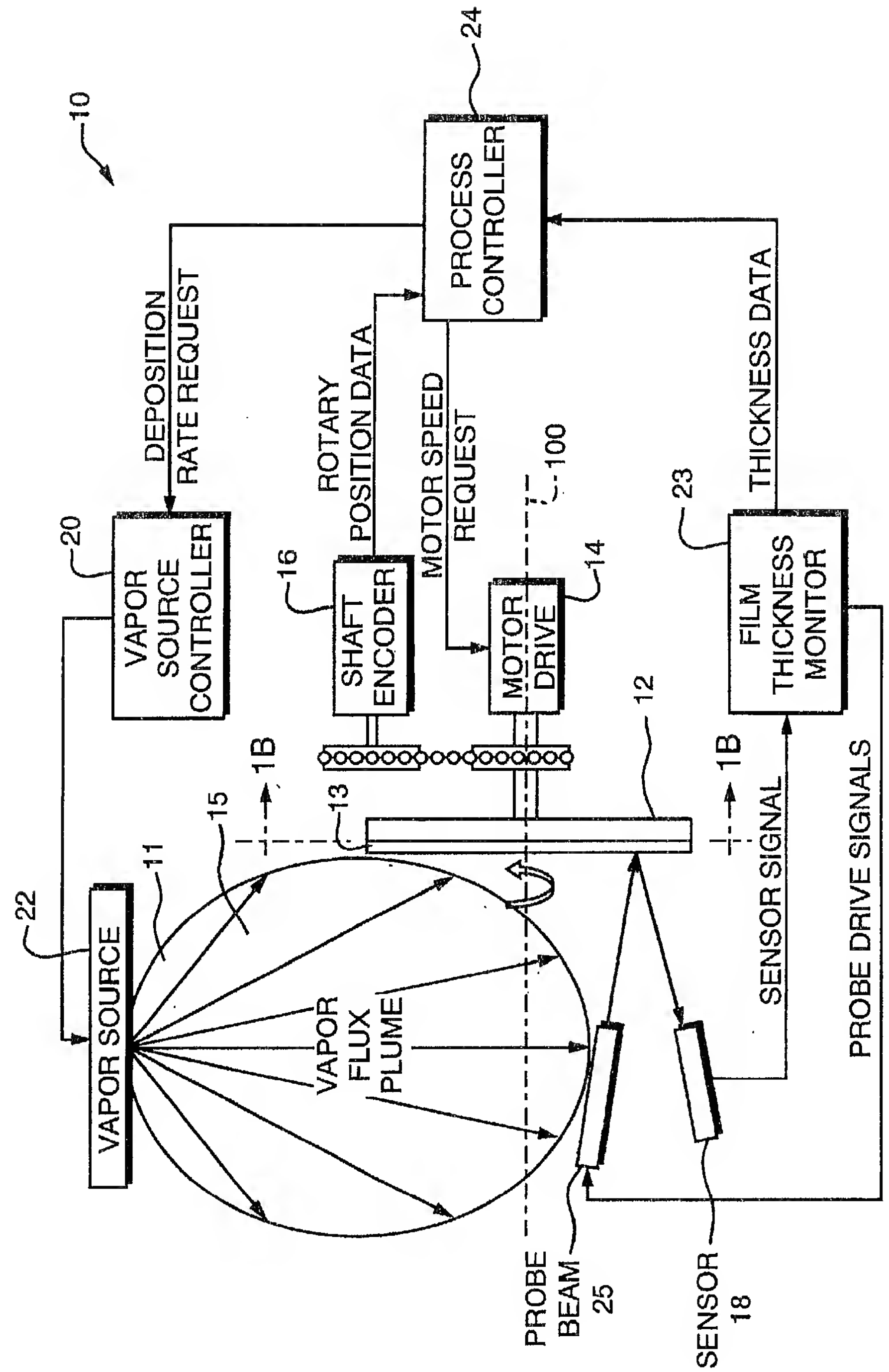

10
24
PROCESS CONTROLLER
DEPOSITION RATE REQUEST
ROTARY POSITION DATA
MOTOR SPEED REQUEST
THICKNESS DATA
20
VAPOR SOURCE CONTROLLER
16
SHAFT ENCODER
14
MOTOR DRIVE
100
23
FILM THICKNESS MONITOR
12
13
1B
1B
15
11
22
VAPOR SOURCE
VAPOR FLUX PLUME
SENSOR SIGNAL
PROBE DRIVE SIGNALS
PROBE BEAM 25
SENSOR 18

FIG. 1A

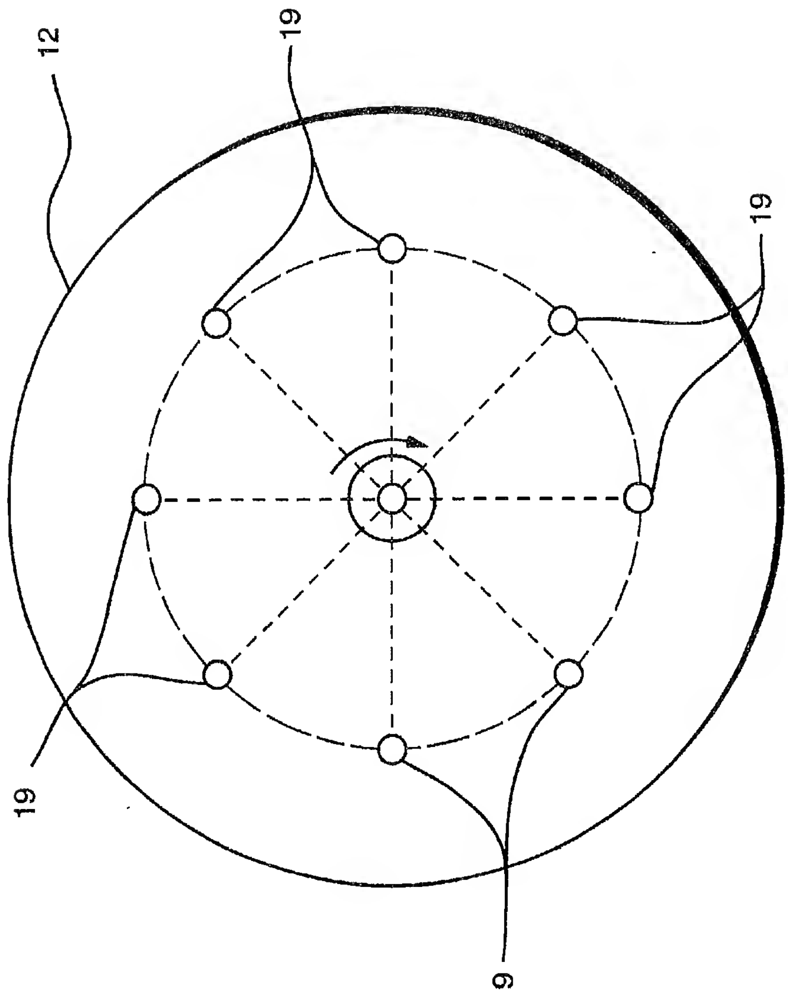


FIG. 1B

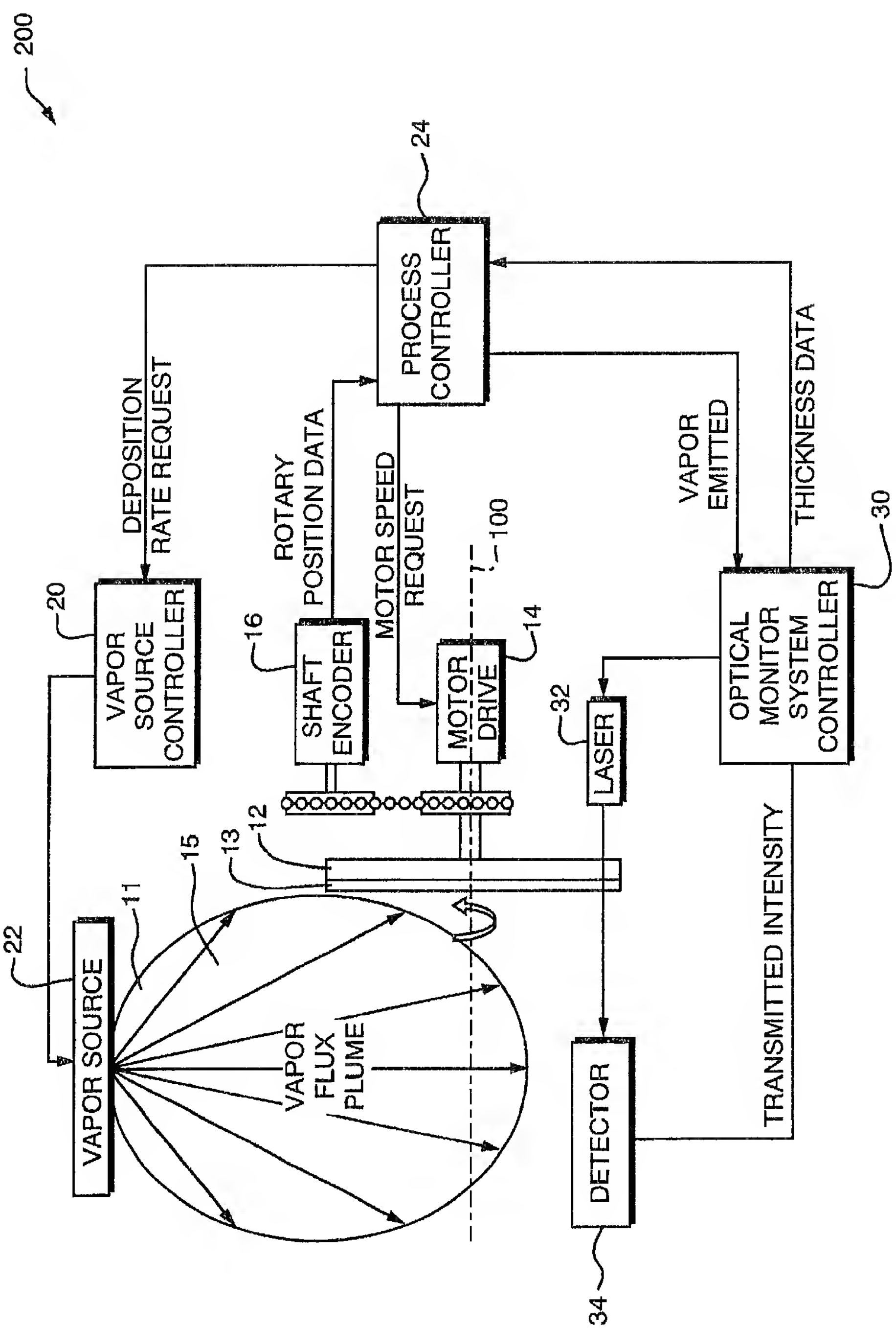

200
PROCESS CONTROLLER
24
DEPOSITION RATE REQUEST
ROTARY POSITION DATA
MOTOR SPEED REQUEST
VAPOR EMITTED
THICKNESS DATA
VAPOR SOURCE CONTROLLER
20
SHAFT ENCODER
16
MOTOR DRIVE
14
100
OPTICAL MONITOR SYSTEM CONTROLLER
30
LASER
32
VAPOR SOURCE
22
11
15
13
12
VAPOR FLUX PLUME
DETECTOR
34
TRANSMITTED INTENSITY

FIG. 2

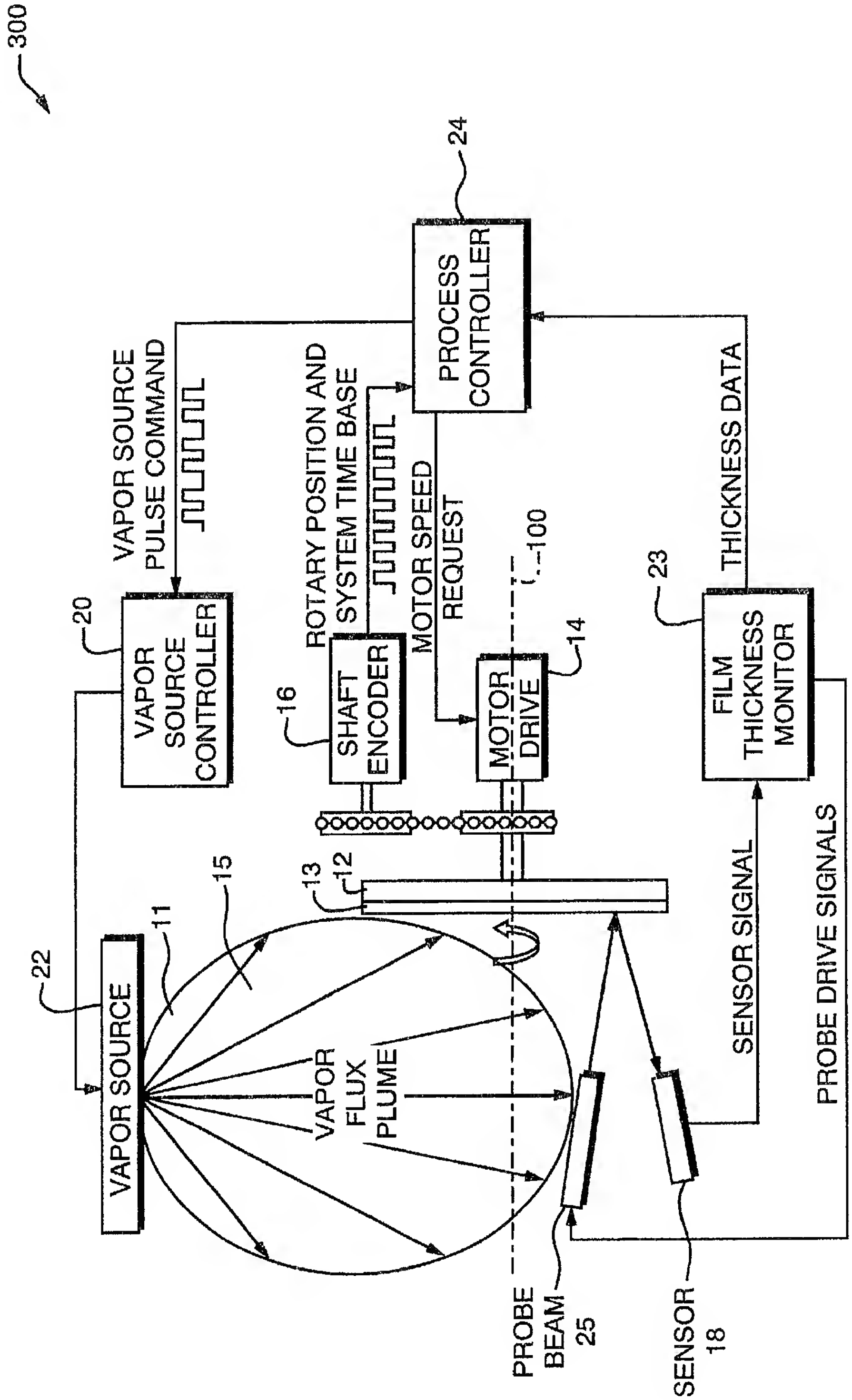

300
24
PROCESS CONTROLLER
VAPOR SOURCE PULSE COMMAND
ROTARY POSITION AND SYSTEM TIME BASE
MOTOR SPEED REQUEST
THICKNESS DATA
100
20
VAPOR SOURCE CONTROLLER
16
SHAFT ENCODER
14
MOTOR DRIVE
23
FILM THICKNESS MONITOR
22
VAPOR SOURCE
11
15
13
12
VAPOR FLUX PLUME
SENSOR SIGNAL
PROBE DRIVE SIGNALS
PROBE BEAM 25
SENSOR 18

FIG. 3

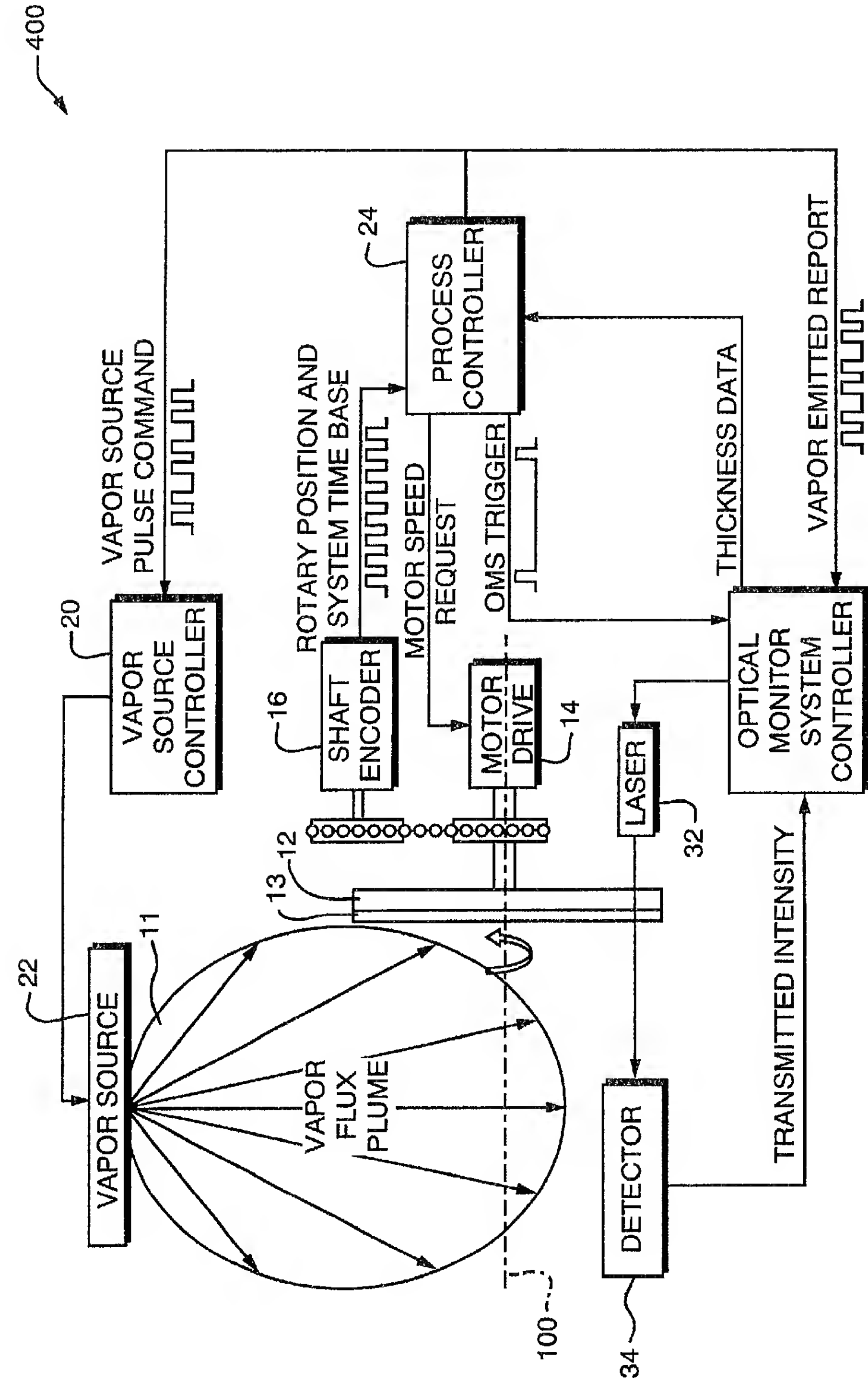
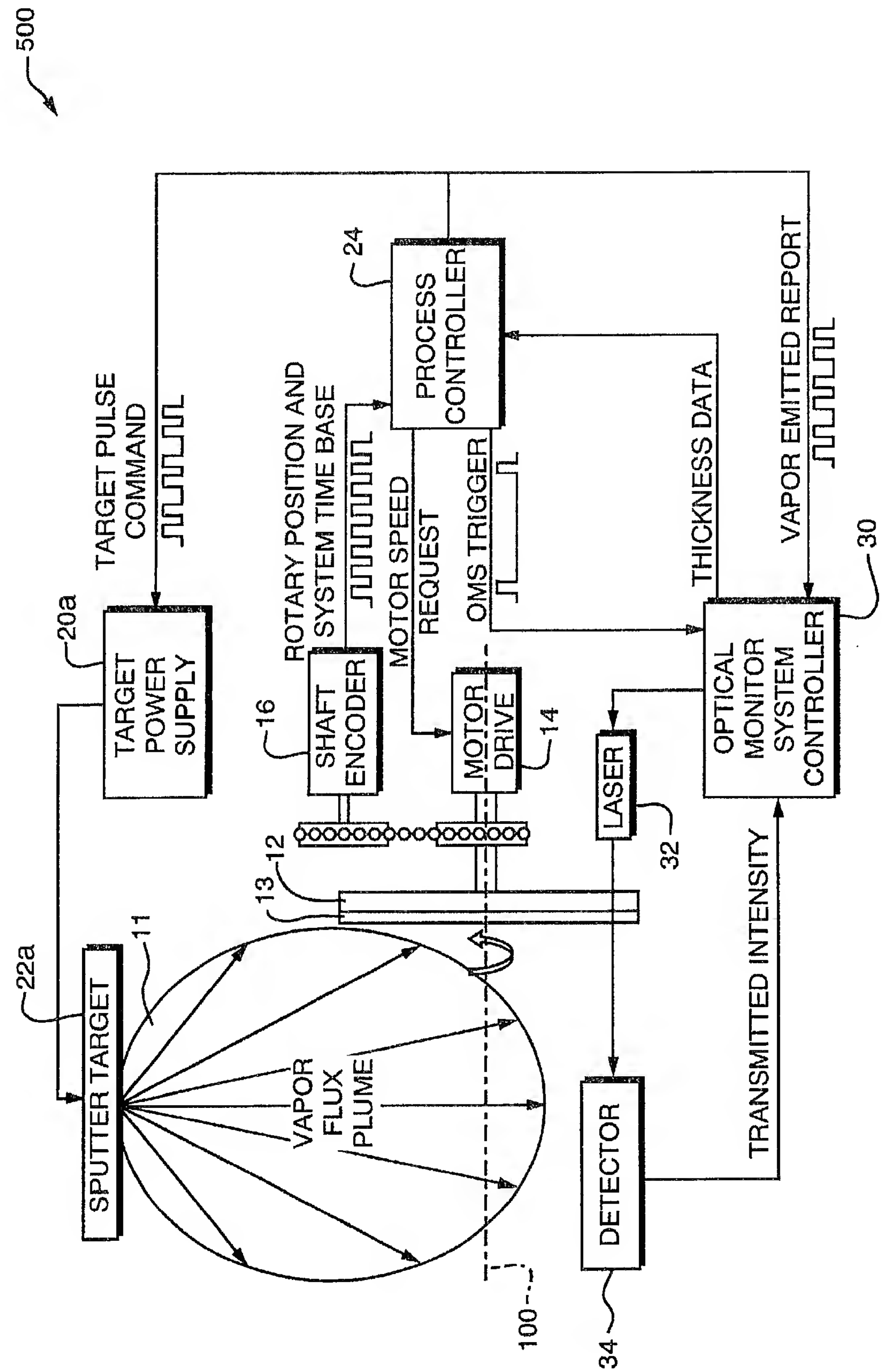

400
VAPOR SOURCE
PULSE COMMAND
20
VAPOR
SOURCE
CONTROLLER
ROTARY POSITION AND
SYSTEM TIME BASE
24
PROCESS
CONTROLLER
MOTOR SPEED
REQUEST
OMS TRIGGER
THICKNESS DATA
VAPOR EMITTED REPORT
30
OPTICAL
MONITOR
SYSTEM
CONTROLLER
16
SHAFT
ENCODER
MOTOR
DRIVE
14
LASER
32
12
13
11
22
VAPOR SOURCE
VAPOR
FLUX
PLUME
DETECTOR
TRANSMITTED INTENSITY
100
34

FIG. 4



500
TARGET PULSE COMMAND
20a
TARGET POWER SUPPLY
22a
SPUTTER TARGET
11
VAPOR FLUX PLUME
100
ROTARY POSITION AND SYSTEM TIME BASE
16
SHAFT ENCODER
24
PROCESS CONTROLLER
MOTOR SPEED REQUEST
OMS TRIGGER
MOTOR DRIVE
14
13
12
LASER
32
DETECTOR
34
THICKNESS DATA
VAPOR EMITTED REPORT
30
OPTICAL MONITOR SYSTEM CONTROLLER
TRANSMITTED INTENSITY

FIG. 5

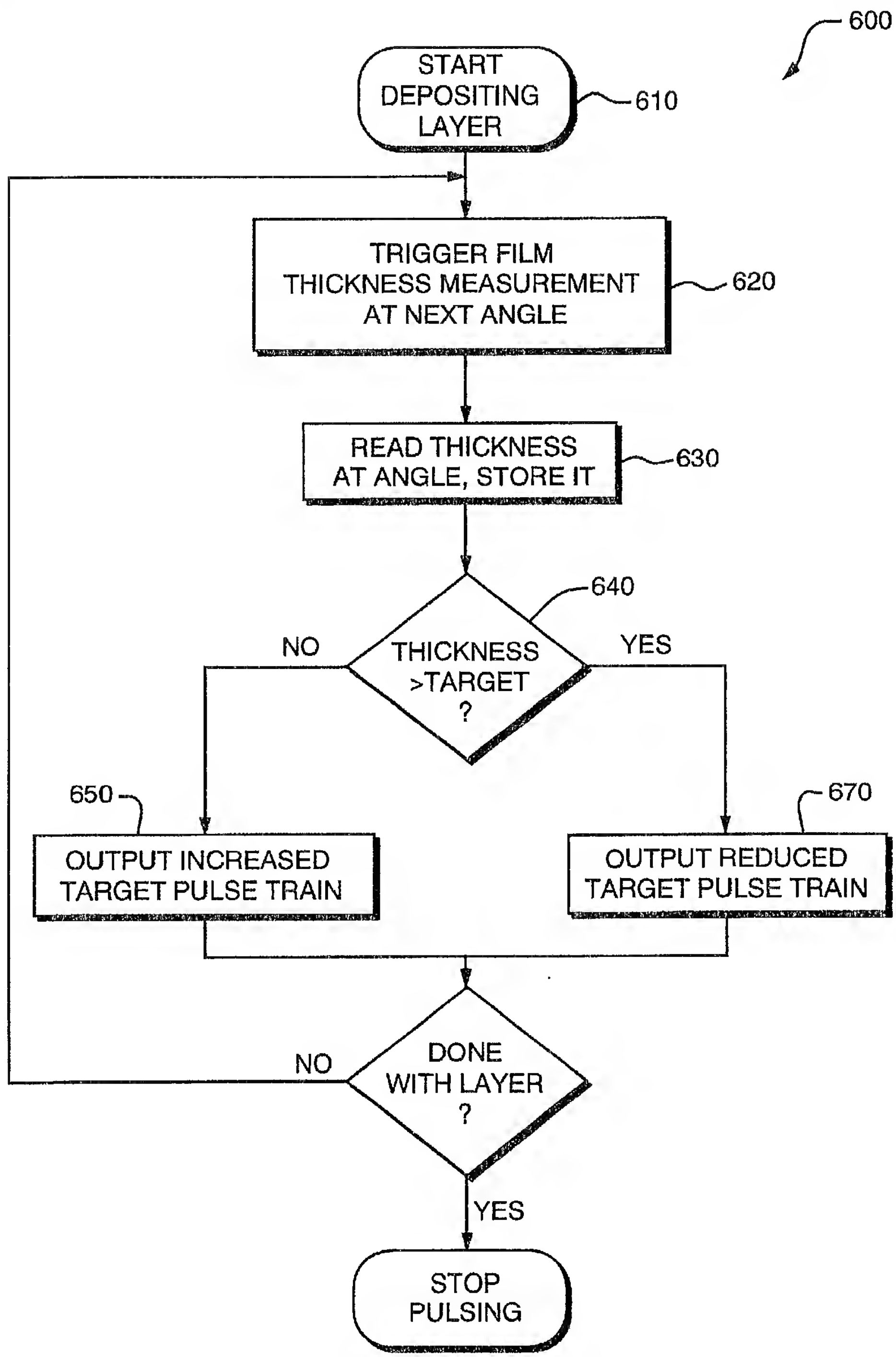

600
START DEPOSITING LAYER
610
TRIGGER FILM THICKNESS MEASUREMENT AT NEXT ANGLE
620
READ THICKNESS AT ANGLE, STORE IT
630
640
THICKNESS >TARGET ?
NO
YES
650
OUTPUT INCREASED TARGET PULSE TRAIN
670
OUTPUT REDUCED TARGET PULSE TRAIN
DONE WITH LAYER ?
NO
YES
STOP PULSING

FIG. 6

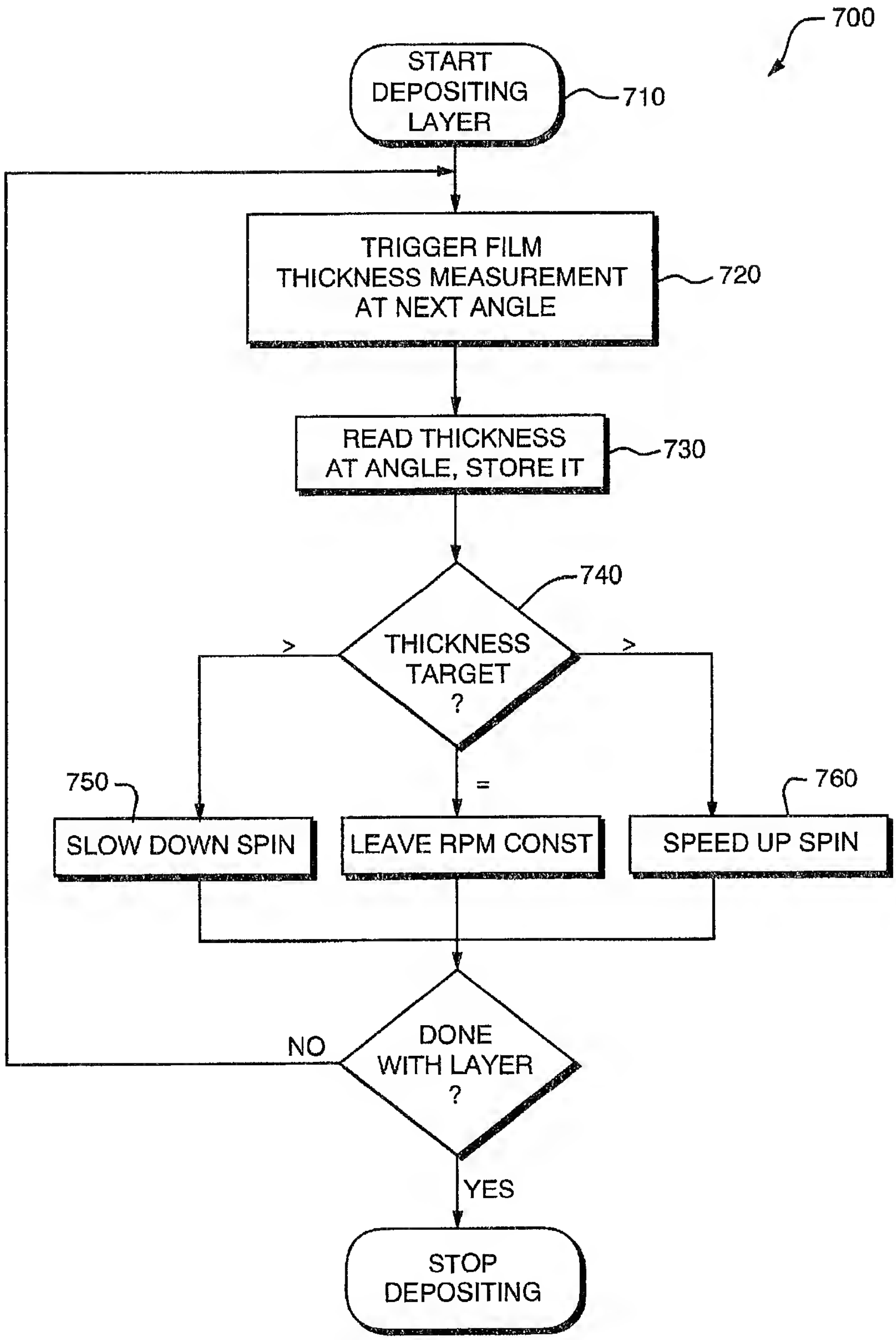

700
START DEPOSITING LAYER
710
TRIGGER FILM THICKNESS MEASUREMENT AT NEXT ANGLE
720
READ THICKNESS AT ANGLE, STORE IT
730
THICKNESS TARGET ?
740
>
=
>
750
SLOW DOWN SPIN
LEAVE RPM CONST
SPEED UP SPIN
760
DONE WITH LAYER ?
NO
YES
STOP DEPOSITING

FIG. 7

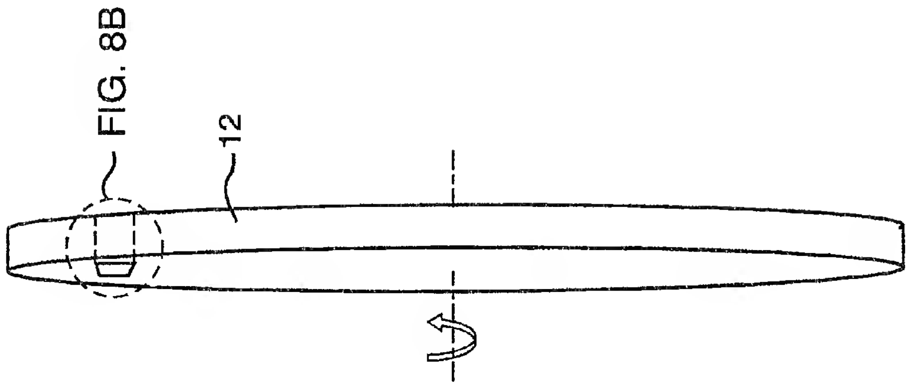


FIG. 8B
12

FIG. 8A

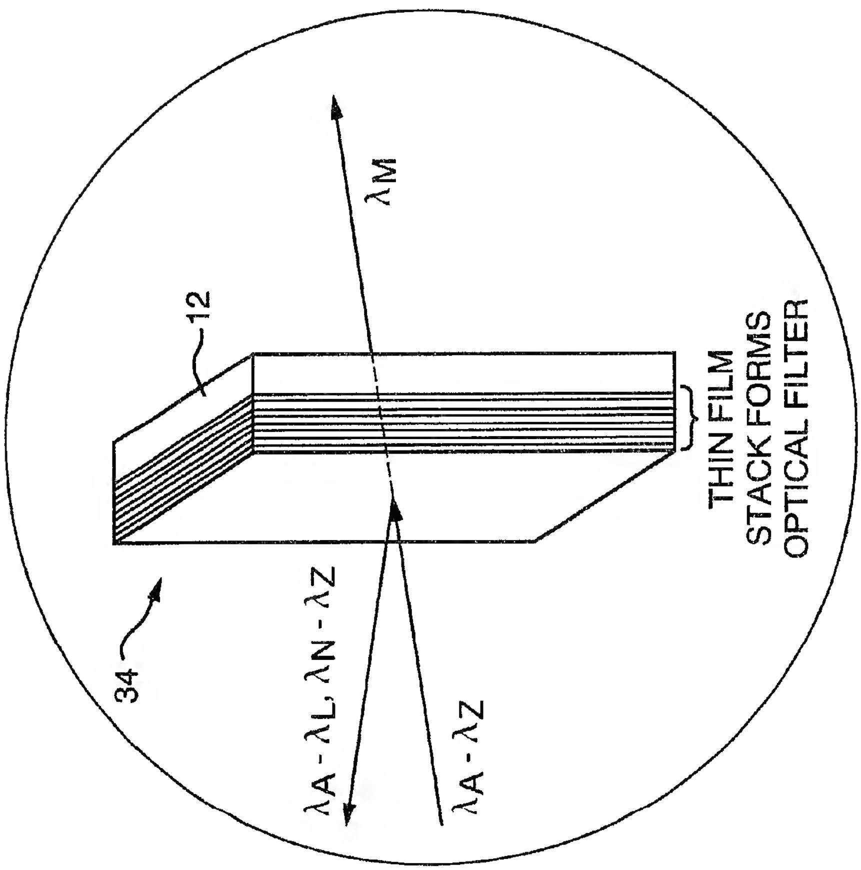

λ_M
12
THIN FILM
STACK FORMS
OPTICAL FILTER
34
$\lambda_A - \lambda_L, \lambda_N - \lambda_Z$
$\lambda_A - \lambda_Z$

FIG. 8B

SYSTEM AND METHOD FOR CONTROLLING DEPOSITION THICKNESS BY SYNCHRONOUSLY VARYING A SPUTTERING RATE OF A TARGET WITH RESPECT TO A POSITION OF A ROTATING SUBSTRATE

FIELD OF INVENTION

The present invention is directed generally to novel systems and methods for performing sputter deposition, and to optical devices manufactured using such systems and methods.

BACKGROUND OF THE INVENTION

It is believed that in vapor deposition systems such as ion beam sputtering, magnetron sputtering, diode sputtering, thermal evaporation, electron beam evaporation, pulsed laser vaporization and cathodic arc vaporization, atoms or molecules ejected from a target are directed toward a substrate disposed on a wafer where they condense to form a film. In most cases, the deposited film shows variation in thickness across the wafer that the user would like to eliminate (for uniform deposition) or control (thickness gradient) to meet the needs of a particular application. It would be beneficial to provide a system that improves control of the deposition thickness on a wafer.

SUMMARY OF THE INVENTION

The present invention is directed to a system and method for controlling a circumferential deposition thickness distribution on a substrate. A motor rotates the substrate and a position sensor senses a rotary position of the substrate. At least one deposition thickness sensor senses the deposition thickness of the film on the substrate at multiple positions on a circumference of a circle centered about an axis of rotation of the substrate. At least one controller drives a vapor source used to emit material for deposition on the substrate. The controller is coupled to the positioning sensor and the deposition thickness sensor. The controller synchronously varies an emission rate of the material from the vapor source with respect to the rotary position of the substrate to control the circumferential deposition thickness distribution.

In accordance with a further aspect, the present invention is directed to a system and method for controlling a circumferential deposition thickness distribution on a substrate. A motor rotates the substrate and a positioning sensor senses a rotary position of the substrate. At least one deposition thickness sensor senses the deposition thickness of the film on the substrate at multiple positions on a circumference of a circle centered about an axis of rotation of the substrate. A target power supply drives a target used to sputter material on the substrate. A process controller is coupled to the positioning sensor, the deposition thickness sensor, and the target power supply. The process controller synchronously varies a sputtering rate of the target with respect to the rotary position of the substrate to control the circumferential deposition thickness distribution.

The invention also includes an optical filter created using the disclosed system and method.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated herein and constitute part of this specification, illustrate presently preferred embodiments of the invention, and, together with the general description given above and the detailed description given below, serve to explain features of the invention. In the Drawings:

FIG. 1A is a schematic diagram of the system for performing vapor deposition using circumferential thickness control according to the present invention;

FIG. 1B is a diagram of a substrate showing the sensing of deposition thickness at multiple positions on the circumference of a substrate, wherein the circumference corresponds to a circle centered about an axis of rotation of the substrate, according to the present invention;

FIG. 2 is a schematic diagram of an alternate embodiment of the system for performing vapor deposition using circumferential thickness control according to the present invention;

FIG. 3 is a schematic diagram of the system for performing vapor deposition using a pulse control scheme and a film thickness monitor according to the present invention;

FIG. 4 is a schematic diagram of an alternate embodiment of the system for performing vapor deposition using a pulse control scheme and an optical monitor system controller according to the present invention;

FIG. 5 is a schematic diagram of an alternate embodiment of the system for performing sputter deposition using a pulse control scheme, a target power supply and an optical monitor system controller according to the present invention;

FIG. 6 is a flow diagram showing the steps of monitoring and controlling the pulse train output of the position sensor by the process controller to control the deposition thickness of the substrate according to the present invention;

FIG. 7 is a flow diagram showing the steps of monitoring and controlling the RPM of the motor drive of the substrate by the process controller to control the deposition thickness of the substrate according to the present invention; and

FIGS. 8A and 8B depict an optical filter formed using the systems and methods of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

There is shown in FIG. 1A, a system **10** for controlling a circumferential deposition thickness distribution on a substrate **12**. A motor **14** rotates the substrate **12** about axis **100**, and a positioning sensor **16**, generally a rotary shaft encoder, senses a rotary position of the substrate **12** during rotation of the substrate. At least one deposition thickness sensor **18** senses the deposition thickness of film material **13** deposited on the substrate **12** at multiple positions **19** (shown in FIG. 1B) on a circumference of a circle centered about an axis **100** of rotation the substrate **12**. Although in the embodiment shown, substrate **12** is circular in shape, it will be understood that a substrate **12** that was square or some other shape could also be used with the present invention. A vapor source controller **20** drives a vapor source **22**. The vapor source **22** creates a vapor flux plume **11** that is disposed proximate the substrate **12**. The vapor flux plume **11** contains material **15** for deposition on the substrate **12** as deposited film material **13**. The vapor source may be created by a target (as shown in FIG. **5**) that is sputtered with high energy ions, a solid charge that evaporates as it is heated, or a chemical vapor deposition source. A process controller **24** is coupled to the motor **14**, the shaft encoder **16**, the deposition thickness sensor **18**, and the vapor source controller **20**. In another embodiment shown in FIG. **5**, the vapor source controller **20** and the vapor source **22** may be a target power supply **20***a* that drives a target **22***a* that is used to sputter material **15** on the substrate **12**.

In the embodiment of FIG. 1, the process controller 24 is coupled to a film thickness monitor 23. It should be recognized by those skilled in the art that the functions of the process controller 24 and film thickness monitor 23 may be combined into a single controller. The film thickness monitor 23 is further coupled to one or more deposition thickness sensors 18 (only one of which is shown in FIG. 1) and one or more probe beams sources 25 (only one of which is shown in FIG. 1), each of which corresponds to one of the deposition thickness sensors 18. Probe drive signals are fed into each probe beam source 25 by the film thickness monitor 23. Beams generated by each probe beam source 25 are reflected or scattered from the substrate and then sensed by a corresponding one of the deposition thickness sensors 18. Sensor signals (having values related to the deposition thickness on the substrate or the thickness of the substrate in combination with any deposited material) from each deposition thickness sensor 18 are fed into the film thickness monitor 23. Thickness data from the film thickness monitor 23 is then fed into the process controller 24 in order to monitor the deposition thickness of material 13 on the substrate. In one embodiment, the process controller 24 associates the thickness data provided by film thickness monitor 23 with rotary positioning data from the shaft encoder 16 in order to map the deposition thickness data to spatial positions on a circumference of substrate 12 during operation of system 10.

In one embodiment, each probe beam source 25 generates a probe beam that strikes multiple positions 19 on a circumference of a circle centered about axis 100 as substrate 12 rotates. This is accomplished, for example, by aiming the probe beam source at a fixed position in space corresponding to a fixed distance from axis 100, and then generating a probe beam targeted at the fixed position periodically as the substrate 12 rotates. By generating the probe beam targeted at the fixed position two or more times during each rotation of the substrate, the present invention is able to sense the deposition thickness of material 13 at multiple positions 19 on a circumference of a circle centered about axis 100 during rotation of the substrate. It will be understood by those skilled in the art that, by using multiple probe beam sources 25 such as the one described above, wherein each of the probe beam sources 25 generates a probe beam targeted at a different fixed position that is at a different distance from axis 100, the present invention is able to sense the deposition thickness of material 13 at multiple positions on the circumference of a plurality of different circles (each having a different radius from axis 100) during rotation of the substrate 12. Rotary position data from shaft encoder 16 is fed into the process controller 24 and associated with each deposition thickness measurement.

In response to the mapped deposition thickness data derived from the signals from thickness monitor 23 and shaft encoder 16, process controller 24 varies the deposition rate of the emitted material 15 from the vapor source 22 synchronously in accordance with the rotary position of the substrate 12. As shown in FIG. 1, vapor flux plume 11, with its depositable material 15, is divergent and is not aimed in an axi-symmetric fashion at substrate 12. Such flux may be formed, for example, by directing an ion current at a given position on a planar target that is not coaxial with the substrate. As a result, as seen in FIG. 1A, the deposition rate of material 15 onto film material 13 on substrate 12 will be higher for portions of the substrate that are closer to the vapor source 22, and lower for portions of substrate 12 positioned farther away from vapor source 22. As a result of this geometry, process controller 24 is able to increase/decrease the deposition rate of material 13 along any given circumferential (or azimuthal) section of substrate 12 by simply slowing down/speeding up the rotation rate of substrate 12 as the given circumferential (or azimuthal) section passes closest to vapor source 22 during rotation of the substrate. Alternatively, in cases where a constant rotation rate is desired, process controller 24 can vary the deposition rate of material 13 at any given circumferential section of substrate 12 by increasing/decreasing the rate of material emitted from source 22 as the given circumferential section passes closest to vapor source 22. It will be understood by those skilled in the art that the deposition rate at any given circumferential section of substrate 22 can therefore be varied by either adjusting the rate of emissions from source 22, the speed of rotation of substrate 12, or combination thereof, as the given circumferential section passes closest to vapor source 22 during each of its rotations.

A second embodiment of a system 200 for controlling a deposition thickness on a substrate 12 is shown in FIG. 2. The system 200 is identical to system 10 as described in FIG. 1A, with the exception that the process controller 24 is coupled to an optical monitoring system controller 30. One or more lasers 32 (only one of which is shown in FIG. 2) are driven by the optical monitoring system 30. One or more detectors, 34 (only one of which is shown in FIG. 2) sense the output of each laser 32 after passage of an output beam through substrate 12. Each detector 34 feeds a sensor signal into the optical monitoring system controller 30 in order to monitor the deposition thickness of material 13 on the substrate, in a manner substantially analogous to the system shown in FIG. 1. However, in the system of FIG. 2, the process controller 24 also provides a vapor-emitted signal that represents the quantity of deposited material on the substrate 12 to controller 30. The vapor emitted signal is a time varying signal that represents the magnitude of material emitted from vapor source 22 during each of a plurality of time segments in which system 200 is operating. In the embodiment discussed below in FIGS. 3–4, the vapor-emitted signal represents a count of a number of pulses provided to the vapor source controller 20 in order to drive vapor source 22. The sum of pulses in the vapor emitted signal over a given time provides a parameter that is proportional to the thickness of the material 15 deposited as film 13 on the substrate 12 over the given time. A constant exists between the number of pulses provided to vapor source controller 20 over a given time and the total thickness of material deposited on the substrate during the given time. The constant (which corresponds to the thickness of material deposited on the substrate for each pulse provided to the vapor source controller) is determined by dividing the thickness value provided by the sensor signal at the end of the given time by the total number of pulses in the vapor emitted signal during the given time. Controller 24 uses this proportionality constant to predict the number of pulses that need to be applied to the vapor source controller in order to reach a desired deposition thickness during operation of the device, thereby preventing the deposition thickness from exceeding the target thickness as a result of overshoot resulting from feedback control.

A third embodiment of a system 300 for controlling a deposition thickness on a substrate 12 is shown in FIG. 3. The system 300 is substantially identical to system 10 as described in the first embodiment. In the system of FIG. 3, a rotary position/system time base signal (e.g., a pulse train output) is generated by the shaft encoder 16. The process controller 24 uses the thickness data (described above in connection with FIG. 1) and the pulse train output to vary the

emission rate of material vapor source 22. In this embodiment, the pulse train output of the shaft encoder 16 is modified by the process controller 24 to generate the signal used to vary the emission rate of the vapor source. In particular, the process controller 24 in essence uses the pulse train from the shaft encoder 16 as the default signal for driving vapor source controller 20, but the process controller omits pulses from the pulse train sent to the vapor source controller in order to vary the emission rate from vapor source 22. Since, in this embodiment, the emission rate of material from vapor source 22 is directly proportional to the number of pulses received by vapor source controller 20 during a given time segment, the omission of pulses from the signal provided to the vapor source controller during any given time segment will serve to decrease the emission rate of material 15 from the vapor source during such time segment. It should be recognized by those skilled in the art that the process controller 24 may vary the emission rate of the vapor source 22 by varying a duty cycle, an amplitude, a frequency or any combination thereof, of the pulse train signal provided to vapor source controller 20.

A fourth embodiment of a system 400 for controlling a deposition thickness on a substrate 12 is shown in FIG. 4. The system 400 is identical to system 300 as shown in FIG. 3, with the exception that the optical monitoring system controller 30, the laser 32, and the detector 34 as shown in FIG. 2 and as described in the second embodiment are employed. In addition, an optical monitor system trigger signal (OMS trigger) is fed from the process controller 24 to the optical monitor system controller 30. The OMS triggers measurements by each laser 32 at multiple points (e.g., positions 19) along a single circumference of the substrate 12 during rotation of the substrate. A further variation to this embodiment shows a coupling of the vapor source command pulse train signal to optical monitoring system 30. Since the vapor source command pulse train signal is proportional to the quantity of material emitted from vapor source 20 during any given time segment, the vapor source command pulse train signal may be used (as described above in FIG. 2) to generate the thickness data supplied to process controller 24.

A fifth embodiment of a system 500 for controlling a deposition thickness on a substrate 12 is shown in FIG. 5. The system 500 is identical to system 400 as shown in FIG. 4, with the exception that a target 20*a* and a target power supply 22*a* are used in place of the more generic vapor source 20 and vapor source controller 22 shown previously.

Referring now to FIG. 6, there is shown a flow diagram detailing the steps of a method 600 for monitoring film thickness and controlling the pulse train output of the position sensor 16 by the process controller 24 to control the deposition thickness on the substrate. In step 610, a layer of material 13 is deposited in an ongoing deposition on the substrate 12 during rotation of the substrate. As the substrate 12 rotates to a trigger angle in step 620, the thickness at that angle is read and then stored in the memory of the process controller (step 630). If the stored thickness is less(or greater) than a predetermined desired thickness (step 640), then the pulse train output to vapor source controller 22 is modified such that the vapor emission rate increases in step 650 (or decreases in step 670) when the circumferential portion of the substrate corresponding to the film thickness measurement is in position close to the vapor source (or target). Once the predetermined thickness of the layer is reached, then pulsing is stopped.

Referring now to FIG. 7, there is shown a flow diagram detailing the steps of a method 700 for monitoring and controlling the RPM of motor drive 14 by process controller 24 to control the deposition thickness of material 13 on the substrate according to the present invention. In step 710, a layer of material is deposited in an ongoing deposition on the substrate 12 during rotation of the substrate. As the substrate 12 rotates to a trigger angle in step 720, the thickness at that angle is read and then stored in the memory of the process controller (step 730). The process controller compares the stored thickness with a predetermined desired thickness in step 740. If the stored thickness is less (or greater) than a predetermined desired thickness, then the substrate rotation speed is modified such that the rotation speed decreases in step 750 (or increases in step 760) when the circumferential portion of the substrate corresponding to the film thickness measurement is in position close to the vapor source (or target). The process is repeated until processing of a given layer of material 13 is complete.

A method for controlling a deposition thickness on a substrate 12 using the system shown in FIG. 1, will now be described. The method comprises the steps of rotating a substrate 12 with a motor 14 and sensing an angular position of the substrate 12 with a shaft encoder 16. At least one deposition sensor 18 senses the deposition thickness of the film 13 on substrate 12 at multiple positions on a circumference of a circle centered about the axis 100 of rotation of the substrate. At least one process controller 24 drives a vapor source 22 used to emit material 15 for deposition on the substrate 12. The process controller 24 is coupled to the motor 14, the shaft encoder 16, the vapor source controller 20, and the deposition thickness sensor 18. The process controller 24 synchronously varies the vapor flux rate of the emitted material 15 with respect to the angular position of the substrate 12 to control the deposition thickness of film 13 around a circumference of the substrate.

The system and process described above may be advantageously used to create an optical filter 35, as shown in FIGS. 8A, 8B when light including $\lambda_A\lambda_Z$ is directed at filter 35, λ_A–λ_L and λ_N λ_Z is reflected and λ_M passes through the filter. When the pesent invention is used to form an optical filter 35, the substrate 12 is preferably formed of a glass wafter, the material deposited on the substrate is alternating layers of tantalum oxide and silicon oxide, and the thickness of the material deposited on the substrate is low-order multiples and/or fractions of the optical thickness at the wavelenth of light that the filter will serve to isolate. The filter 35 may be used in the form deposited or it may be further processed by sawing, grinding, trimming, back-thinning, polishing, mounting, bonding or other means to incorporate the filter into an optic assembly. It will be evident to practioners of the art that substrates other than glass may be used, that smaller substtrate pieces may be attatched to the wafer 12 for deposition of the filters on the smaller pieces, that deposited materials other than tantalum oxide and silicon oxide could be used for the filter, as long as the refractive index contrast was sufficiently large, and that a variety of differing optical stack designs might be employed to create a filter.

It will be appreciated by those skilled in the art that changes could be made to the embodiments described above without departing from the broad inventive concept thereof. For example, although several individual controllers are shown in various embodiments, it will be understood that the functions of such multiple controllers could be performed by a single controller. It is understood, therefore, that this invention is not limited to the particular embodiments disclosed, but is intended to cover modifications within the spirit and scope of the present invention as defined in the appended claims.

What is claimed is:

1. A system for controlling a circumferential deposition thickness distribution on a substrate comprising:

(a) a motor that rotates the substrate;

(b) a position sensor that senses a rotary position of the substrate;

(c) at least one deposition thickness sensor that senses the deposition thickness of the substrate at multiple positions on a circumference of a circle centered about an axis of rotation of the substrate;

(d) a target power supply that drives a target used to sputter material on the substrate;

(e) a process controller coupled to the position sensor, the at least one deposition thickness sensor, and the target power supply; and

(f) wherein the process controller synchronously varies a sputtering rate of the target with respect to the rotary position of the substrate to control the circumferential deposition thickness distribution.

2. The system of claim 1, wherein the at least one deposition thickness sensor is an optical sensor.

3. The system of claim 1, wherein the deposition thickness is determined by the process controller in response to an output of the at least one deposition thickness sensor and a target bias signal that is proportional to the sputtering rate.

4. The system of claim 1, wherein the process controller varies the sputtering rate by varying a target bias signal.

5. The system of claim 4, wherein the process controller modifies a pulse train output by the position sensor to generate the target bias signal which changes a deposition rate on the substrate when a portion of the rotating substrate proximate the target has a deposition thickness that requires modification to match a desired deposition thickness.

6. The system of claim 5, wherein the pulse train output by the position sensor is modified by the process controller to generate the target bias signal by adding or omitting pulses from the target bias signal.

7. The system of claim 1, wherein the process controller varies the sputtering rate by varying a duty cycle of a target bias signal.

8. The system of claim 1, wherein the process controller varies the sputtering rate by varying an amplitude of a target bias signal.

9. The system of claim 1, wherein the process controller varies the sputtering rate by varying a frequency of a target bias signal.

10. A method for controlling a circumferential deposition thickness distribution on a substrate, the method comprising the steps of:

(a) rotating the substrate with a motor;

(b) sensing a rotary position of the substrate with a position sensor;

(c) sensing the deposition thickness of the substrate at multiple positions on a circumference of a circle centered about an axis of rotation of the substrate with at least one deposition thickness sensor; and

(d) synchronously varying a sputtering rate of a target with respect to the rotary position of the substrate, in response to outputs of the position sensor and the at least one deposition thickness sensor, to control the circumferential deposition thickness distribution on the substrate.

11. A system for controlling a circumferential deposition thickness distribution on a substrate comprising:

(a) a motor that rotates the substrate;

(b) a position sensor that senses a rotary position of the substrate;

(c) at least one deposition thickness sensor that senses the deposition thickness of the substrate at multiple positions on a circumference of a circle centered about an axis of rotation of the substrate;

(d) at least one source controller that drives a vapor source used to emit material for deposition on the substrate, said at least one source controller being coupled to the position sensor and the at least one deposition thickness sensor; and

(e) wherein the at least one source controller synchronously varies an emission rate of material from the vapor source with respect to the rotary position of the substrate to control the circumferential deposition thickness distribution.

12. The system of claim 11, wherein the at least one source controller comprises a vapor source controller that drives the vapor source, and a process controller coupled to the vapor source controller, the position sensor and the at least one deposition thickness sensor, wherein the process controller synchronously varies the emission rate of material from the vapor source with respect to the rotary position of the substrate to control the circumferential deposition thickness distribution.

13. A method for controlling a circumferential deposition thickness distribution on a substrate comprising:

(a) rotating a substrate with a motor;

(b) sensing a rotary position of the substrate with a position sensor;

(c) sensing the deposition thickness of the substrate at multiple positions on a circumference of a circle centered about an axis of rotation of the substrate with at least one deposition thickness sensor; and

(d) synchronously varying an emission rate of material from a vapor source with respect to the rotary position of the substrate, in response to outputs of the position sensor and the at least one deposition thickness sensor, to control the circumferential deposition thickness distribution.

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